AD NUMBER
AD374231
CLASSIFICATION CHANGES
TO: **UNCLASSIFIED**
FROM: **CONFIDENTIAL**
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 30 JUN 1966. Other requests shall be referred to Air Force Rocket Propulsion Lab., Research and Technology Div., Attn: RPPR-STINFO, Edwards AFB, CA 93523.**
AUTHORITY
AFRPL ltr dtd 7 May 1973 AFRPL ltr dtd 7 May 1973

GENERAL DECLASSIFICATION SCHEDULE

IN ACCORDANCE WITH

DOD 5200.1-R & EXECUTIVE ORDER 11652

THIS DOCUMENT IS:

Subject to General Declassification Schedule of Executive Order 11652-Automatically Downgraded at 2 Years Intervals- DECLASSIFIED ON DECEMBER 31, 1972

BY

Defense Documentation Center

Defense Supply Agency

Cameron Station

Alexandria, Virginia 22314

SECURITY MARKING

The classified or limited status of this report applies to each page, unless otherwise marked.
Separate page printouts MUST be marked accordingly.

CONFIDENTIAL

AFRPL TR-66-156 TC5-238-6-6

374231

HOT GAS SECONDARY INJECTION THRUST VECTOR CONTROL DEMONSTRATION PROGRAM PROJECT 2000 (U)

QUARTERLY TECHNICAL REPORT NO. 1

CONTRACT AF 04(611)-11408

30 June 1966

Prepared for

HEADQUARTERS
AIR FORCE FLIGHT TEST CENTER
AIR FORCE SYSTEMS COMMAND
Edwards Air Force Base, California

THIOKOL CHEMICAL CORPORATION
WASATCH DIVISION
Brigham City, Utah

CONFIDENTIAL

SPECIAL NOTICES

Qualified users may obtain copies of this report from the Defense Documentation Center.

This report may be reproduced to satisfy needs of U.S. Government agencies. No other reproduction is authorized except with permission of Air Force Flight Test Center, Edwards AFB, California.

Do not return this copy. When not needed, destroy in accordance with pertinent security regulations.

Foreign announcement and dissemination by the Defense Documentation Center is not authorized.

CONFIDENTIAL

AFRPL TR-66-156

TC5-238-6-6

Copy No. 2?

HOT GAS SECONDARY INJECTION THRUST VECTOR CONTROL DEMONSTRATION PROGRAM PROJECT 2000 (U)

QUARTERLY TECHNICAL REPORT NO. 1

CONTRACT AF 04(611)-11408

30 June 1966

Prepared by

THIOKOL CHEMICAL CORPORATION
WASATCH DIVISION
Brigham City, Utah

Paul D. Nance, Manager
Large Motor Development

Publications No. 666-11742

0716-64-1084

CONFIDENTIAL

FOREWORD

This first quarterly technical report covers the work performed under Contract AF 04(611)-11408, "Hot Gas Secondary Injection Thrust Vector Control Demonstration Program (U)," for the period 15 Feb thru 31 May 1966.

This program (designated Project 623A) is under the overall direction of 1/Lt. George Kirby, USAF/RPMCH, Project Engineer, Air Force Rocket Propulsion Laboratory, Edwards AFB, California. Mr. Paul D. Nance, Manager, Large Motor Development, is the Wasatch Division program manager for Thiokol Chemical Corporation. Mr. M. N. Fuentes, Head, Special Engineering Projects, is the project engineer.

This report contains no classified information extracted from other classified documents. The report was submitted on 30 Jun 1966.

UNCLASSIFIED ABSTRACT

This program was established by the Air Force and Thiokol Chemical Corporation to design, develop, and demonstrate a hot gas secondary injection thrust vector control system (HGSITVC) for large solid propellant rocket motors. The program was initiated on 15 Feb 1966. Phase I of the program is concerned with the design, analysis, and optimization of a 156 in. diameter motor HGSITVC system. The data from this baseline design will be used to design six test pintle valves for demonstration on 65 in. diameter test motors. Phase II consists of designing a four-valve 120 in. diameter motor HGSITVC system using the basic designs and design data developed under Phase I. The 120 in. diameter test motor will be designed, fabricated, and tested to demonstrate four full scale 156 in. diameter motor pintle valves. The pintle valve design will use a proven tungsten-to-tungsten valve seating arrangement and a pressure balance technique to minimize actuation force requirements. A baseline 156 in. diameter demonstration test motor which uses available proven MINUTEMAN hardware was designed this first quarter. The test motor will expose the full scale 156 in. pintle valve to simulated flow and operational pressure environments. In addition, the propellant for the demonstration test motor was tailored to define the required formulation, and the major components for the first Phase I test were ordered. Four satisfactory orifice forgings were shipped.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

LIST OF ILLUSTRATIONS (Cont)

LIST OF TABLES

SECTION I

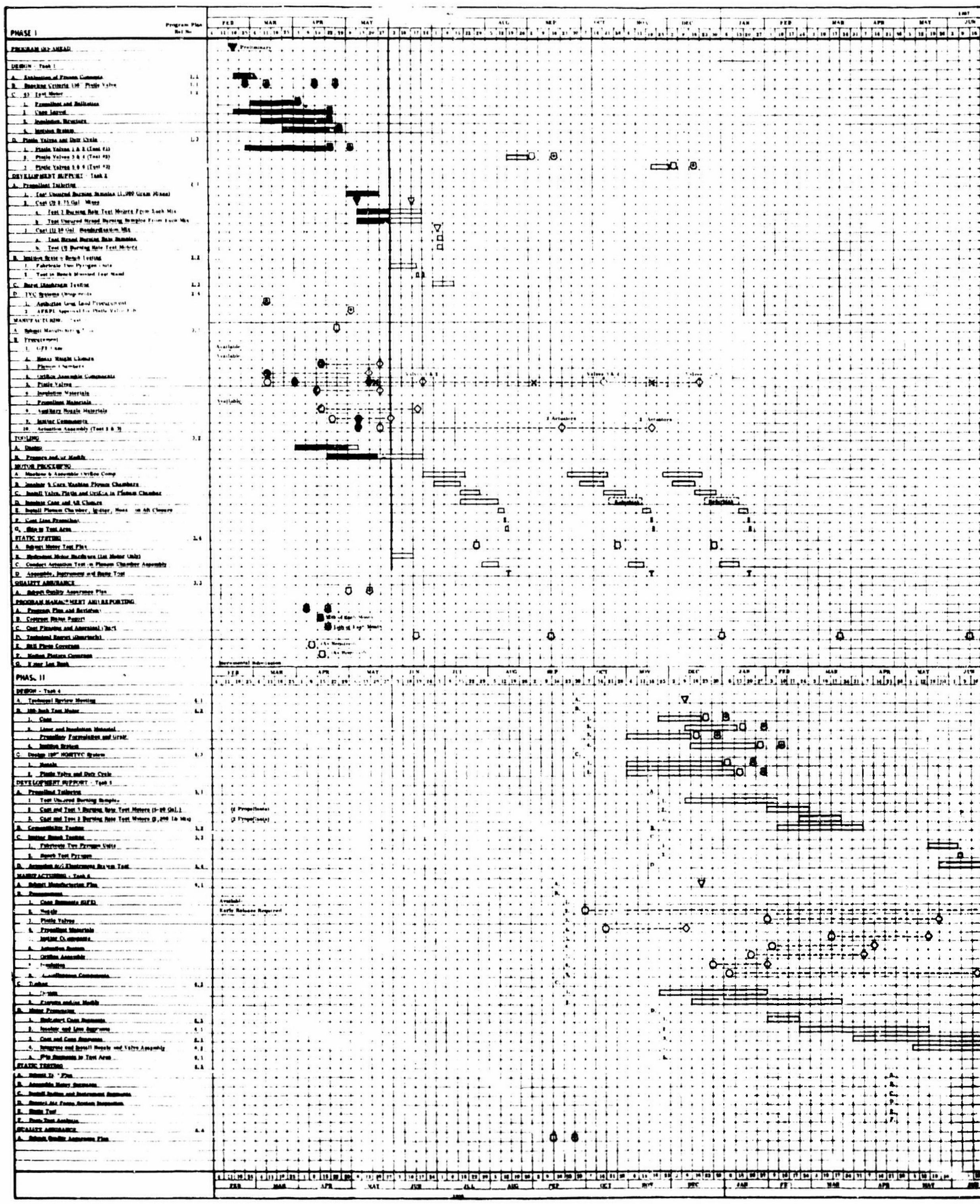
INTRODUCTION AND SUMMARY

This Quarterly Technical Progress Report provides a review of the work accomplished by Thiokol Chemical Corporation from 15 Feb 1966 through 31 May 1966 for the Air Force Flight Test Center, Air Force Systems Command, Edwards AFB, California, under Contract AF 04(611)-11408.

This program was established to develop a submerged hot gas secondary injection thrust vector control (HGSITVC) system for large solid propellant rocket motors. The program has two major phases. Phase I includes the design of a baseline 156 in. rocket motor and HGSITVC system. A components development pintle valve will be designed and demonstrated on three 65 in. diameter test motors. Each demonstration test will include two full scale 156 in. motor pintle valves. Phase II includes the design of a quarter scale baseline test motor to be fitted with a submerged nozzle containing four full scale hot gas valves. This motor will be designed using 120 in. diameter hardware.

A. PROGRAM SCHEDULE

The program schedule presented in Figure 1 defines the scope and schedule of the events in Phases I and II of this program. The three Phase I tests are scheduled for August, November, and January. Phase I program status is identified by the dark overlay in the program schedule, which indicates the completion of design effort supporting the first subscale test motor. The propellant tailoring and procurement status are proceeding satisfactorily and will support the static test of the first TU-521 test motor during the week of 19 August.



Figure

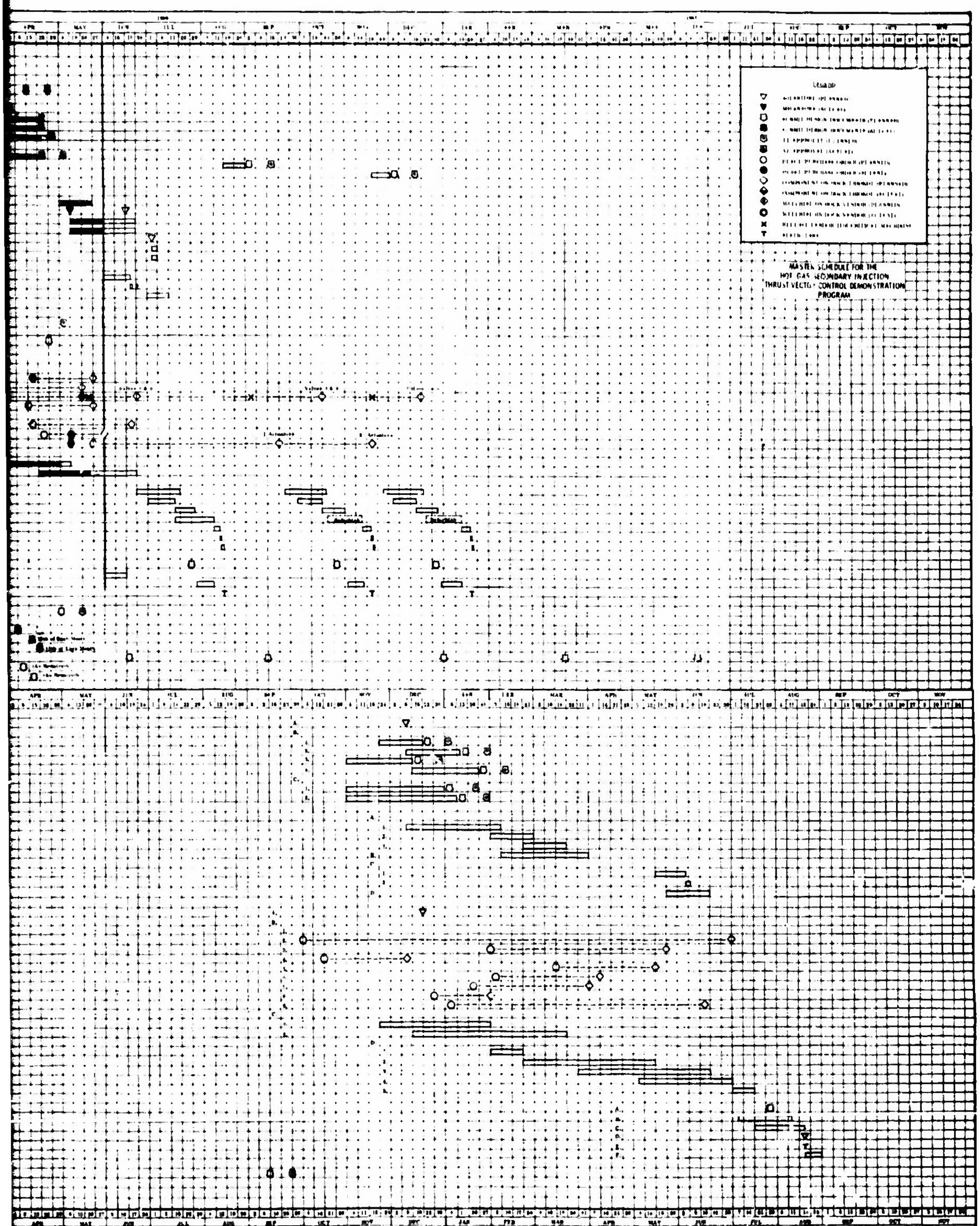


Figure 1. Program Schedule

2

The Phase II effort will be initiated in October 1966. The 120 in. test motor and HGSITVC system will be designed, fabricated, and tested as indicated in Figure 1 .

The program will culminate with the static test of the large motor HGSITVC system on the 120 in. demonstration test motor during August 1967.

B. STATUS SUMMARY

The baseline 156 in. motor designed during this first quarter provides a thrust of 1,898,000 lb for 120 sec at an average operating pressure of 700 psia. The motor contains a composite PBAA ammonium perchlorate aluminum propellant (designated TP-H1113) based upon present 156 in. motor demonstrated technology. This baseline motor design is being used as the foundation for designing the large motor HGSITVC system.

Pintle valve technology previously demonstrated under the Stage I MINUTEMAN production support program and other government sponsored programs has been fully used to design a baseline HGSITVC system. This baseline system has a 7.5 in. diameter pintle and a seating orifice with a 6.5 in. diameter throat. The hot gas valve is pressure balanced to minimize the size of the actuation system and uses two percent thoriated tungsten for the critical pintle and orifice seating components. The valve has been designed to operate at an average pressure of 700 psia and will stand peak pressures up to 1,000 psia. The pintle valve flow rate is approximately 103 lb/sec at 700 psia. The baseline TVC system uses 16 hot gas valves at an injection location of $x/L = 0.5$ and will provide a side force ratio of 0.08.

A demonstration test pintle valve design has been completed for the Phase I testing. This pintle valve design uses the baseline pintle and orifice assembly and has been designed for an average operating pressure of 700 psia. Two of these pintle valves will be demonstrated on the first of three development test motors. Test pintle valves for the first motor have been designed to use external actuation and will be mounted directly to the test chamber. Test motors 2 and 3 will test valves internal actuation and mounting similar to that of the baseline HGSITVC system.

The 65 in. diameter demonstration test motor is designated TU-521. It uses available 65 in. diameter subscale MINUTEMAN test hardware. The propellant grain is an end burning configuration with 6,000 to 12,000 lb of uncured propellant. A PYROGEN ignition system mounted in the aft closure will provide motor ignition. To maintain an average chamber pressure of 700 psia for the predetermined test time, an auxiliary nozzle will be used along with two full scale pintle valves. The motor will maintain a pressure of 700 psia with one of the pintle valves or the auxiliary nozzle flowing full. A duty cycle has been defined for the first Phase I test motor, which will expose the first demonstration test pintle valve to less than half of the baseline HGSITVC flow requirement of 2,000 pounds. Flow will be increased in successive tests until the full flow requirement is demonstrated.

The uncured TP-H1113 propellant for the Phase I test motors was tailored from an existing formulation and small laboratory mix burning rate data were obtained. A target strand burning rate of 0.526 in./sec at 700 psia was established.

An available MINUTEMAN 65 in. diameter closure is being modified for attachment to the auxiliary nozzle, two plenum chambers, and a PYROGEN igniter. Modification is approximately 75 percent complete. Hydrotest tooling and components will be available to hydrotest the modified closure, plenum chamber, and auxiliary nozzle assembly during June. Process planning for the TU-521.01 motor has been completed and motor manufacturing will be initiated during June.

Major components for the first Phase I test were ordered during this first quarter. The following items are now on order: tungsten forgings from Taylor Forge & Pipe Works, PT graphite from Carborundum Graphite Products Division, and the pintle valves from Cleveland Pneumatic Tool Co. Initial tungsten forgings were processing on 16 May. Four satisfactory orifice forgings have been shipped. Difficulty has been experienced in obtaining pintle shell forgings due to poor tooling performance.

SECTION II

PHASE I--LARGE HOT GAS VALVE DEVELOPMENT

A. PHASE I DESIGN

1. DESIGN, ANALYSIS, AND OPTIMIZATION OF 156 INCH MOTOR HGSITVC SYSTEM

a. Design Criteria and Requirements--The following design criteria, which are based on the RFP requirements, were used to size the valves for the 156 in. diameter HGSITVC motor.

1. Thrust, 1,800,000 lbf.
2. Chamber pressure, 700 psia (nominal).
3. Expansion ratio, 8:1.
4. Nozzle half-angle, 15 deg.
5. Nozzle throat diameter, 48 in. (nominal).
6. Firing duration, 120 sec (minimum).
7. Vectoring response rate, 0.5 cps.
8. Ratio of single quadrant side force to maximum sea level axial force for single quadrant of TVC system of 0.08 for all values of axial thrust up to 1,800,000 lbf.
9. Side impulse requirements of 1.1 percent of total impulse, which may occur in any quadrant.
10. No valve leakage when shut.

The selection of optimum injection parameters was based on tradeoff studies conducted using analytical techniques developed under Contract AF 04(611)-9075, "Hot Gas Secondary Injection TVC Design Criteria."

1. Injection port location of X/L = 0.5.
2. Angle of injection perpendicular to nozzle wall.
3. Four valves/quadrant.
4. Sixteen valvos.
5. Injection Mach number of 1.5.

Design emphasis was placed on a 120 in. motor, which will demonstrate the feasibility of the large submerged hot gas valves. The system requirements for the 120 in. demonstration motor are listed below.

1. Thrust, 450,000 lbf.
2. Chamber pressure, 700 psi (nominal).
3. Expansion ratio, 8:1.
4. Nozzle half-angle, 15 deg.
5. Nozzle throat diameter, 22.4 in. (nominal).
6. Firing duration, 120 sec (minimum).
7. Vectoring response rate, 0.5 cps.
8. Ratio of single quadrant side force to maximum sea level axial force for single quadrant injection of TVC system equal to 0.07 (after removal of expected test stand and data acquisition errors) must be demonstrated for each valve. (This value corresponds to 0.08 when applied to the 156 in. diameter motor system.)
9. Side impulse requirements of 1.1 percent of total impulse, which may occur in any quadrant.
10. No valve leakage when shut.

The injection system parameters selected will be consistent with those for the 156 in. motor.

1. Injection location of X/L = 0.5.
2. Injection angle perpendicular to the nozzle wall.
3. One valve quadrant.
4. Four valves.
5. Injection Mach number of 1.5.

The number of valves per quadrant and the total number of valves deviated from those of the 156 in. motor system to demonstrate the full scale valves and obtain similar force ratios.

In addition to these system design criteria, general valve design criteria were also established.

1. Noneroding pintle and orifice.
2. Proven materials and fabrication.
3. High reliability.
4. Low cost.
5. Simple design and construction.
6. Minimum weight.
7. Minimum actuation loads.

These criteria were used in the detailed design of the hot gas valves during this first quarter.

b. <u>TU-519 (156 in.) Motor Design</u>--A baseline 156 in. motor was designed as a basis for evaluating the hot gas secondary injection thrust vector control system (HGSITVC) and as assurance that the HGSITVC system would be compatible with a 156 in. motor. Motor design parameters and ballistics characteristics were defined to initiate component design and analyses for establishing an optimum flightweight HGSITVC system design for 156 in. motor application.

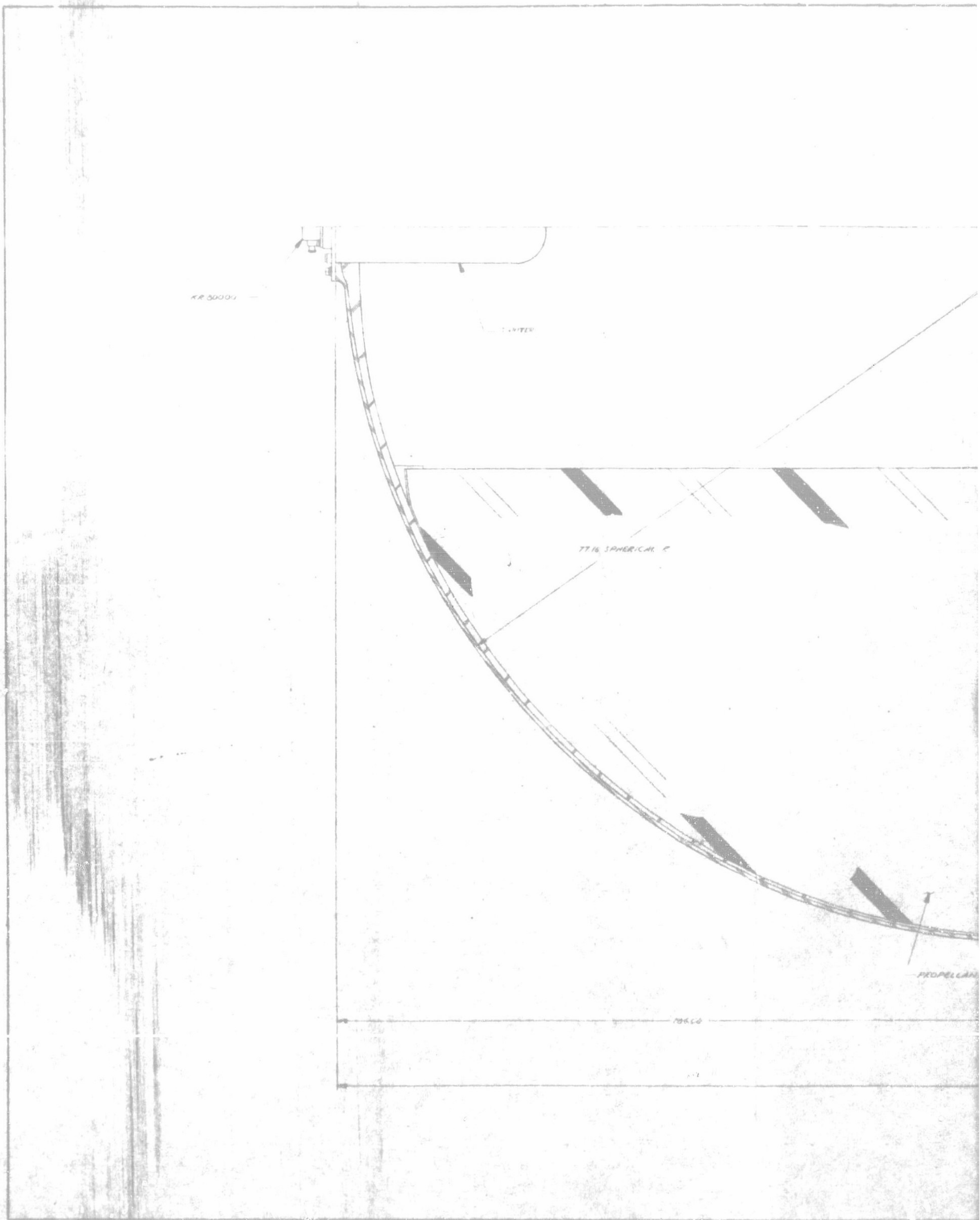
The 156 in. diameter motor incorporates a segmented, steel case (with segmented propellant grain) and an ablative, fixed, submerged nozzle. The motor produces an average thrust of approximately 1.9 x 10^6 lbf thrust during a web time of 120 seconds. A slightly regressive thrust-time history is produced that can be modified by including or deleting inhibitor in the slot areas between segments to be compatible with either first stage booster applications or space vehicle strapon application such as TITAN III. The component design is patterned after the designs developed in the Air Force 156-3 and 156-7 motor programs successfully completed by Thiokol. Figure 2 presents a layout of the 156 in. diameter motor and HGSITVC system.

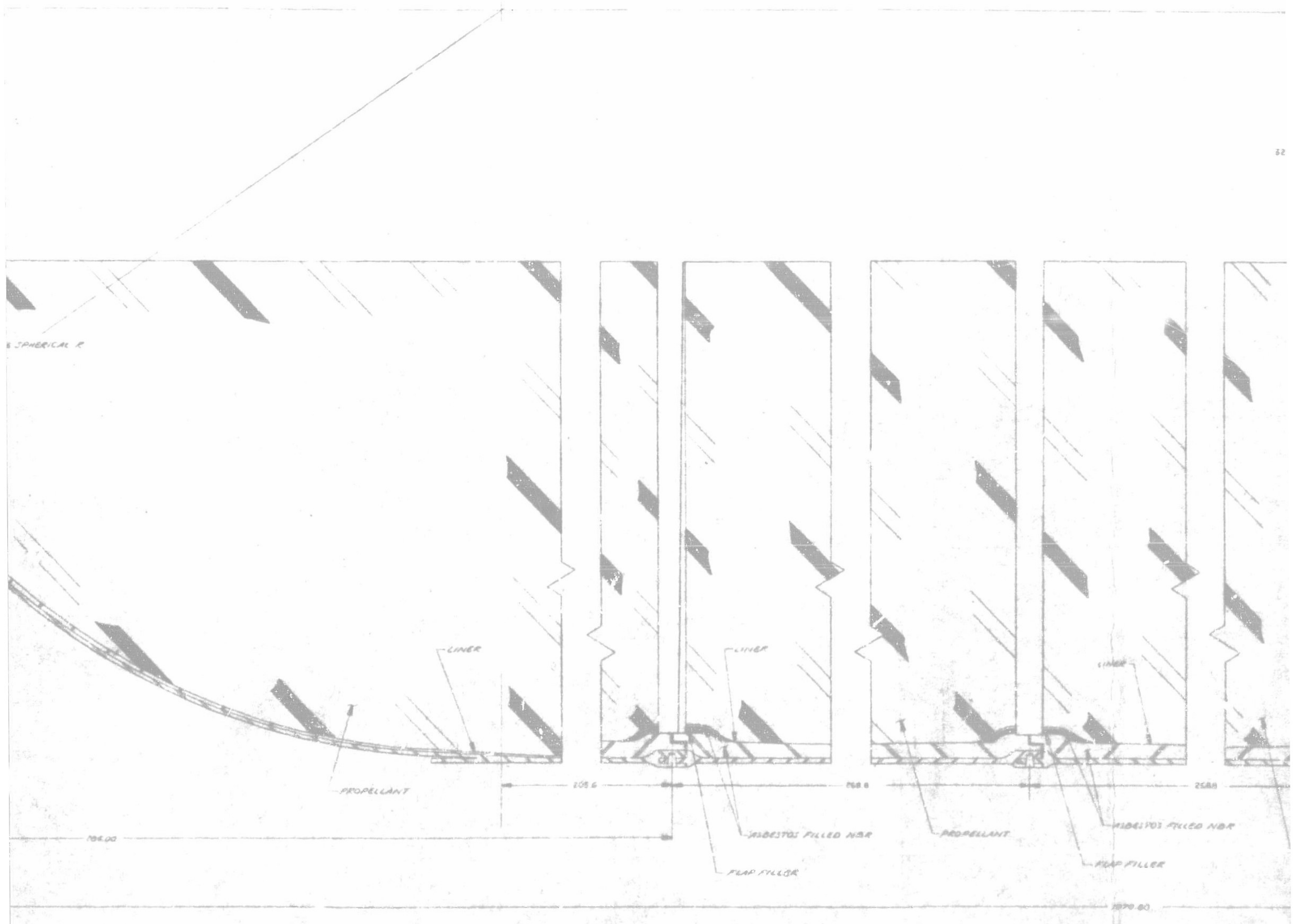
The propellant formulation consists of 13.65 percent HB polymer and curing agent, 70.0 percent ammonium perchlorate, 16 percent aluminum powder, and 0.35 percent iron oxide. This propellant, with slight iron oxide variations, has been used in the MINUTEMAN, and PERSHING and Air Force 156-3 and 1[illegible]-7 motor programs. This propellant experience indicates that a high level of reproducibility of both physical and ballistic properties can be achieved.

The propellant configuration consists of a forward segment, two cylindrically perforated center segments, and an aft segment modified to accommodate the submerged nozzle and hot gas injection system. The motor web fraction is 0.66 and is limited by a minimum port area to a throat area of 1.23:1. The volumetric loading density of the motor is 0.86.

The grain design incorporates a 3 in. nominal slot between the propellant faces of each segment joint. Inhibitor is applied to one face of the forward slot to achieve a slightly regressive thrust-time history. The thrust-time history can be made progressive, neutral, or more regressive (to be compatible with various applications) merely by varying the number of slot faces that are inhibited.

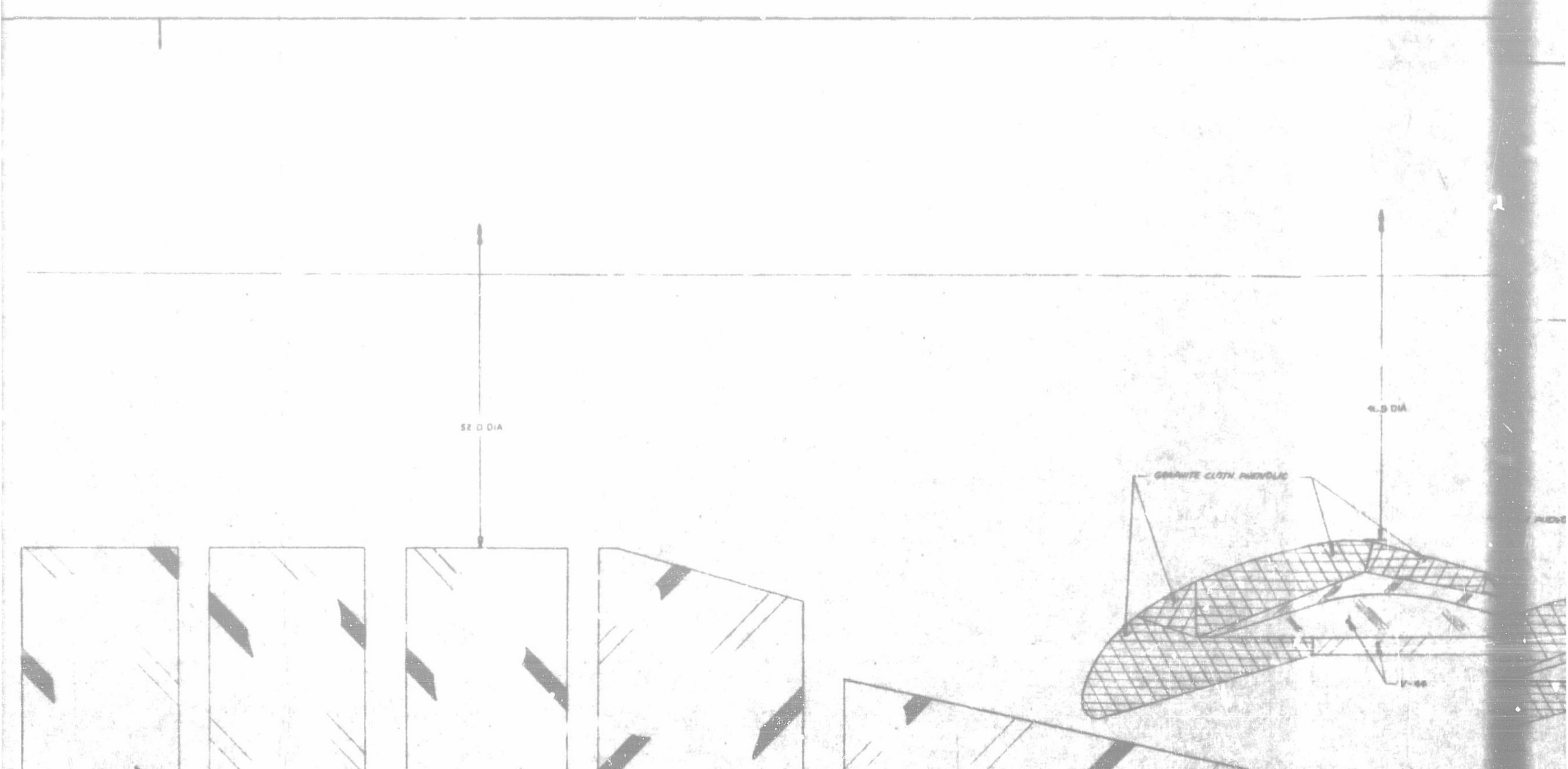
The motor will produce a total impulse of 224.8 x 10^6 lbf-sec at sea level conditions and at 80°F over an action time of 123 seconds. The average action time sea level thrust is 1.828 x 10^6 lbf. The predicted ballistic performance (pressure



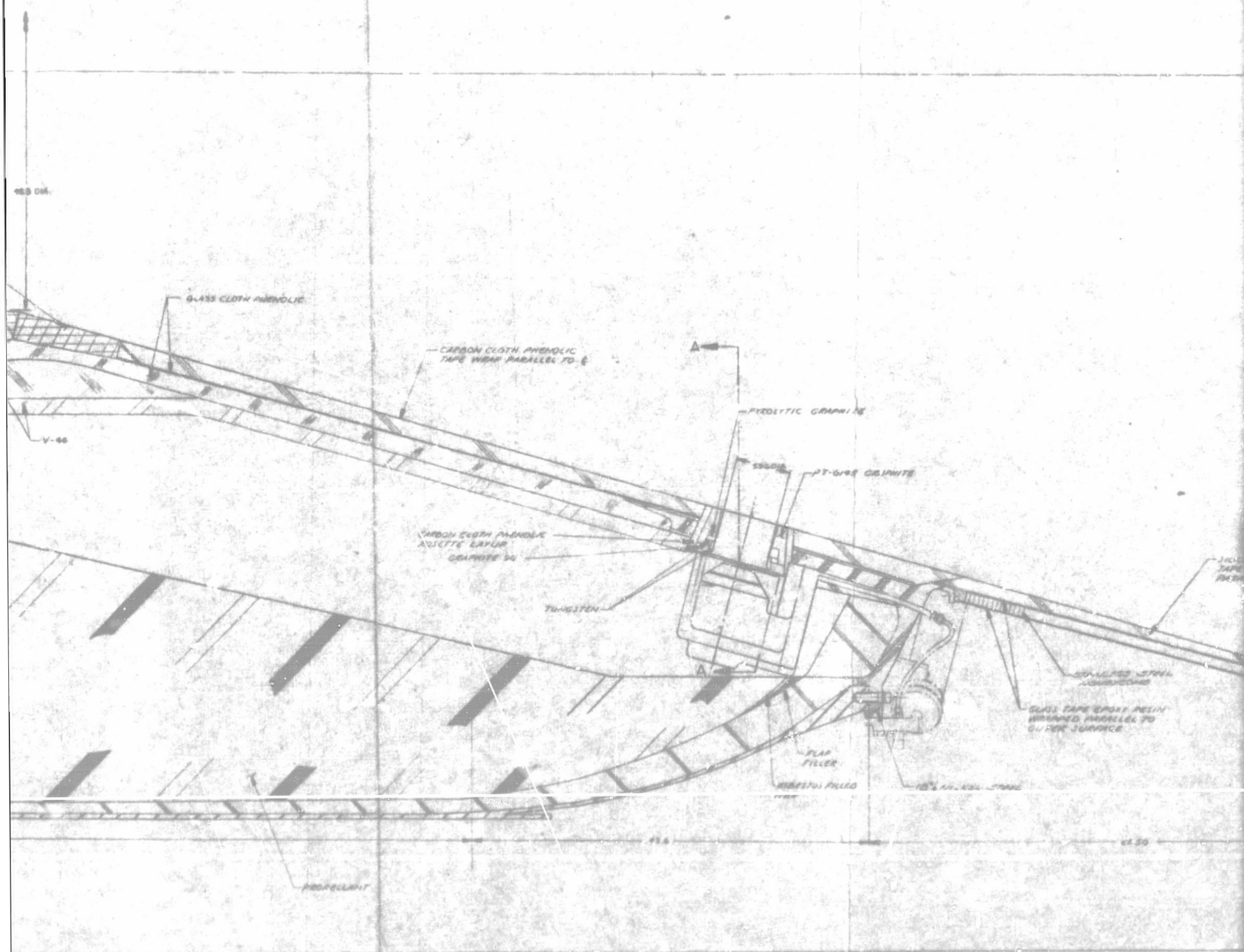

SPHERICAL R
LINER
PROPELLANT
LINER
ASBESTOS FILLED NBR
FLAP FILLER
PROPELLANT
LINER
ASBESTOS FILLED NBR
FLAP FILLER
205.6
784.00

TUL 11,368

2



52.0 DIA
GRAPHITE CLOTH PHENOLIC
LINER
PROPELLANT
ASBESTOS FILLED NBR
FLAP FILLER
26.88
1070.80
TUL 11368



GLASS CLOTH PHENOLIC
CARBON CLOTH PHENOLIC
TAPE WRAP PARALLEL TO ℄
V-44
PYROLYTIC GRAPHITE
PT-0148 GRAPHITE
CARBON CLOTH PHENOLIC
ROSETTE LAYUP
TUNGSTEN
FLAP
FILLER
GLASS TAPE EPOXY RESIN
WRAPPED PARALLEL TO
OUTER SURFACE
PROPELLANT
A

TM-1368

4

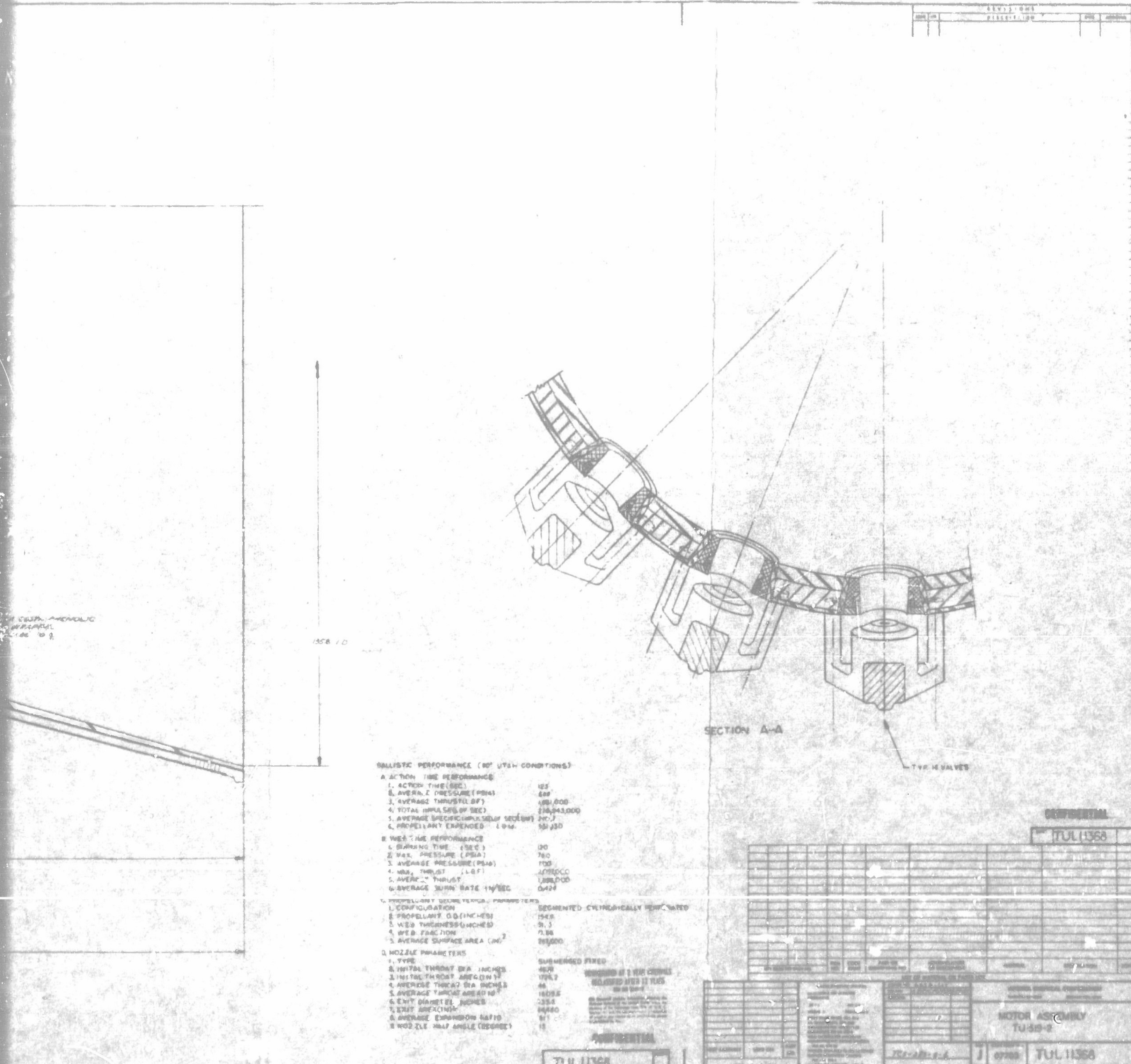


Figure 2. 156 Inch Motor Hot Gas SITVC System

5

end thrust traces) are presented in Figures 3 and 4 . The general motor design parameters and ballistics performance are shown in Table I.

c. Baseline Pintle Valve System--The baseline valve design is shown in Figure 5 . The valve uses a movable pintle protected by a fixed external housing. The valve assembly is mounted to the submerged section of a highly submerged nozzle by three legs located 120 deg apart. The valve orifice is mounted in the submerged section of the nozzle. Axial motion of the pintle is controlled by an internally mounted hydraulic actuator.

(1) Pintle--The pintle is designed to be noneroding on its flow metering surfaces and to seat on its orifice when closed, to eliminate valve leakage. To meet these two conditions, a tungsten shell which serves as a structural member as well as a noneroding flow metering surface was selected for the outer diameter of the pintle. This shell is retained by a threaded retention ring which transmits the actuation loads from a steel connecting link to the tungsten shell. The retention ring is separated from the connecting link by a glass cloth phenolic bearing ring. The steel connecting link transmits actuation loads between the tungsten shell and the internally mounted actuator housing. The outer diameter of this member also serves as a dynamic sealing surface which separates a cavity within the valve housing from the external chamber pressure. The outer tungsten shell is protected from overheating by a carbon cloth phenolic sleeve. The internal actuator is protected by a composite PTB graphite and silica cloth phenolic valve body which also serves as a support structure for the outer tungsten shell.

The valve body has five small holes which connect the pintle cavity within the valve housing with the pintle tip surface to provide a pressure balance between the tip and the cavity. This technique was used to achieve reduced actuation loads; however, it results in hot exhaust gases being drawn into and exhausted out of the cavity behind the pintle as it actuates. This influx and expulsion of gases requires all steel structural members and actuator components which exist in this area to be insulated. Silica phenolic, asbestos phenolic, and V-44 rubber were selected as insulation for all steel components as shown in Figure 5.

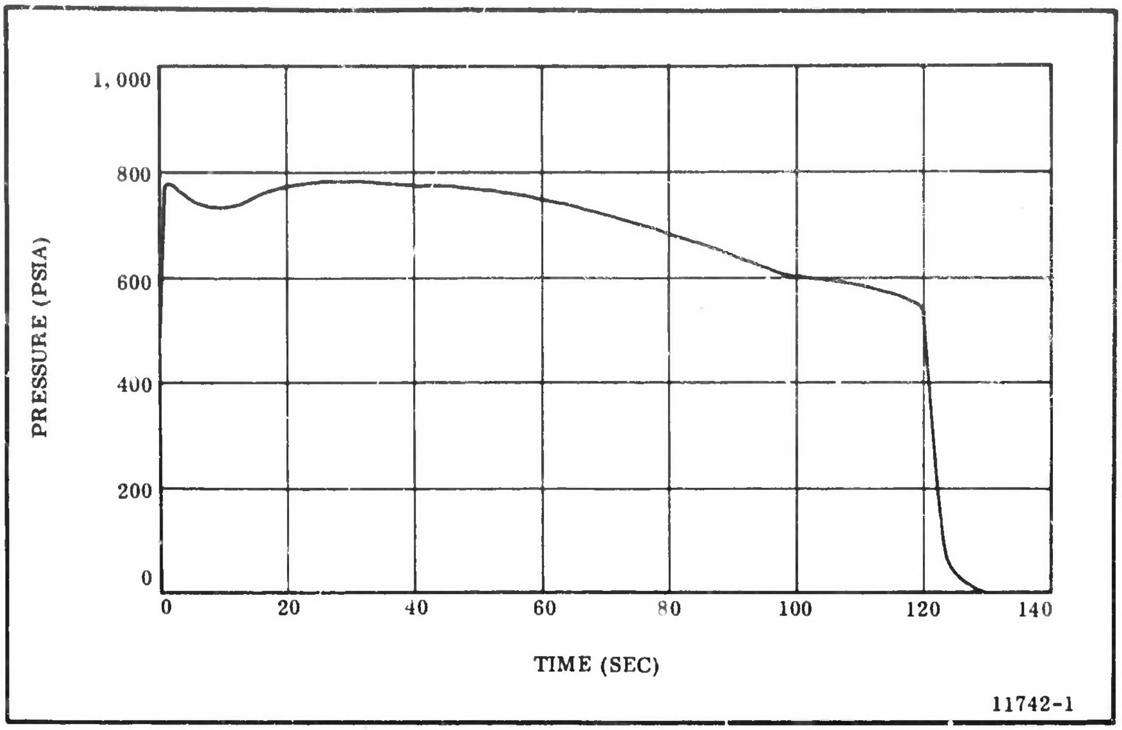


Figure 3. TU-519 Motor Chamber Pressure vs Time

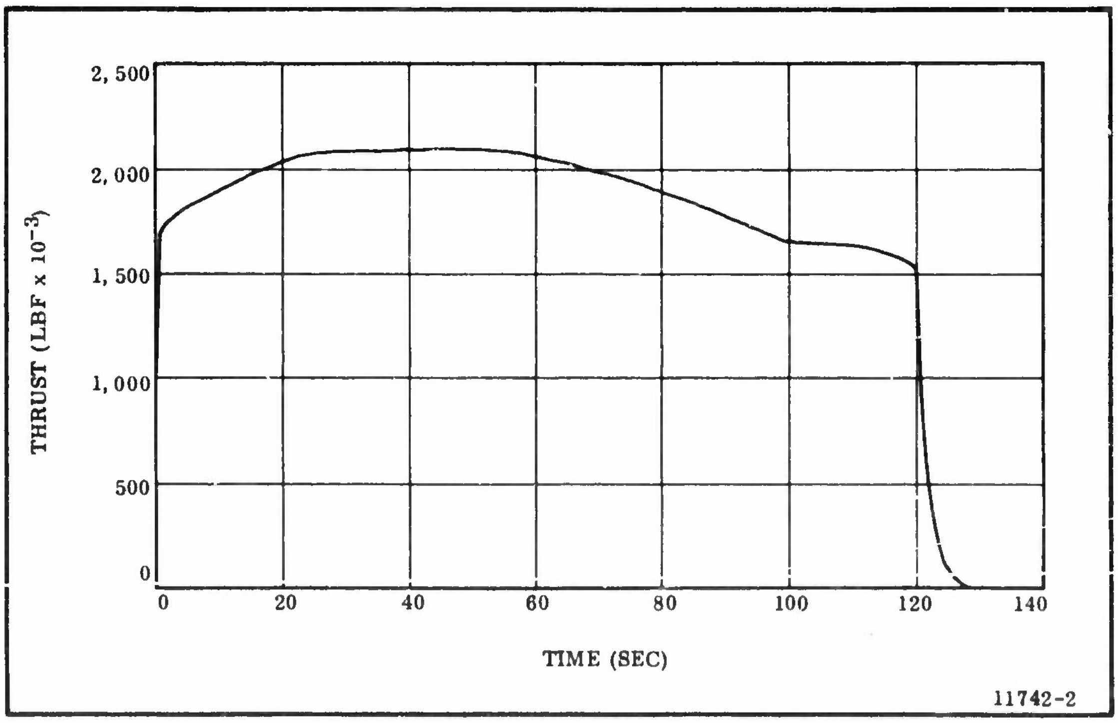
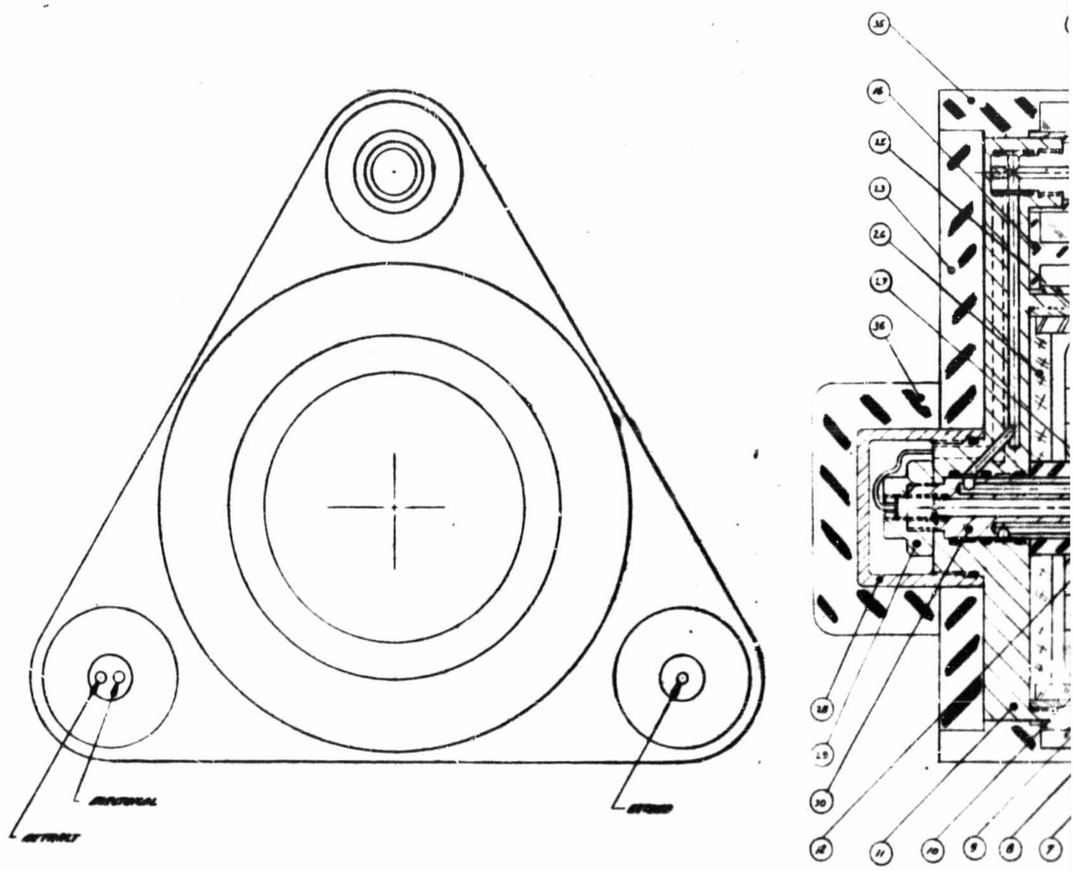


Figure 4. TU-519 Motor Thrust vs Time (Utah Conditions)

TABLE I

TU-519 DESIGN PARAMETERS

Ballistic Performance (80°F, Utah Conditions)	
Web Time Performance	
Burning Time (sec)	120.0
Maximum Pressure (psia)	780
Average Pressure (psia)	700
Maximum Thrust (lbf) (S. L. = 2, 064, 000)	2, 097, 000
Average Thrust (lbf) (S. L. = 1, 865, 000)	1, 898, 000
Average Burning Rate (in. /sec)	0.428
Action Time Performance	
Action Time (sec)	123.0
Average Pressure (psia)	688
Average Thrust (lbf) (S. L. = 1, 828, 000)	1, 861, 000
Total Impulse (lbf-sec)	228, 943, 000
Average Specific Impulse (lbf-sec/lbm)	240.7
Propellant Expended (lbm)	951, 150
Propellant Geometrical Parameters	
Configuration	Segmented Cylindrically Perforated
Propellant Outside Diameter (in.)	154.6
Web Thickness (in.)	51.3
Web Fraction	0.66
Average Surface Area (in.)	287, 600
Nozzle Parameters	
Type	Submerged Fixed
Initial Throat Diameter (in.)	46.91
Initial Throat Area (sq in.)	1, 728.2
Average Throat Diameter (in.)	4, 800
Average Throat Area (sq in.)	1, 809.6
Exit Diameter (in.)	135.8
Exit Area (sq in.)	14, 480
Average Expansion Ratio	8:1
Nozzle Half Angle (deg)	15



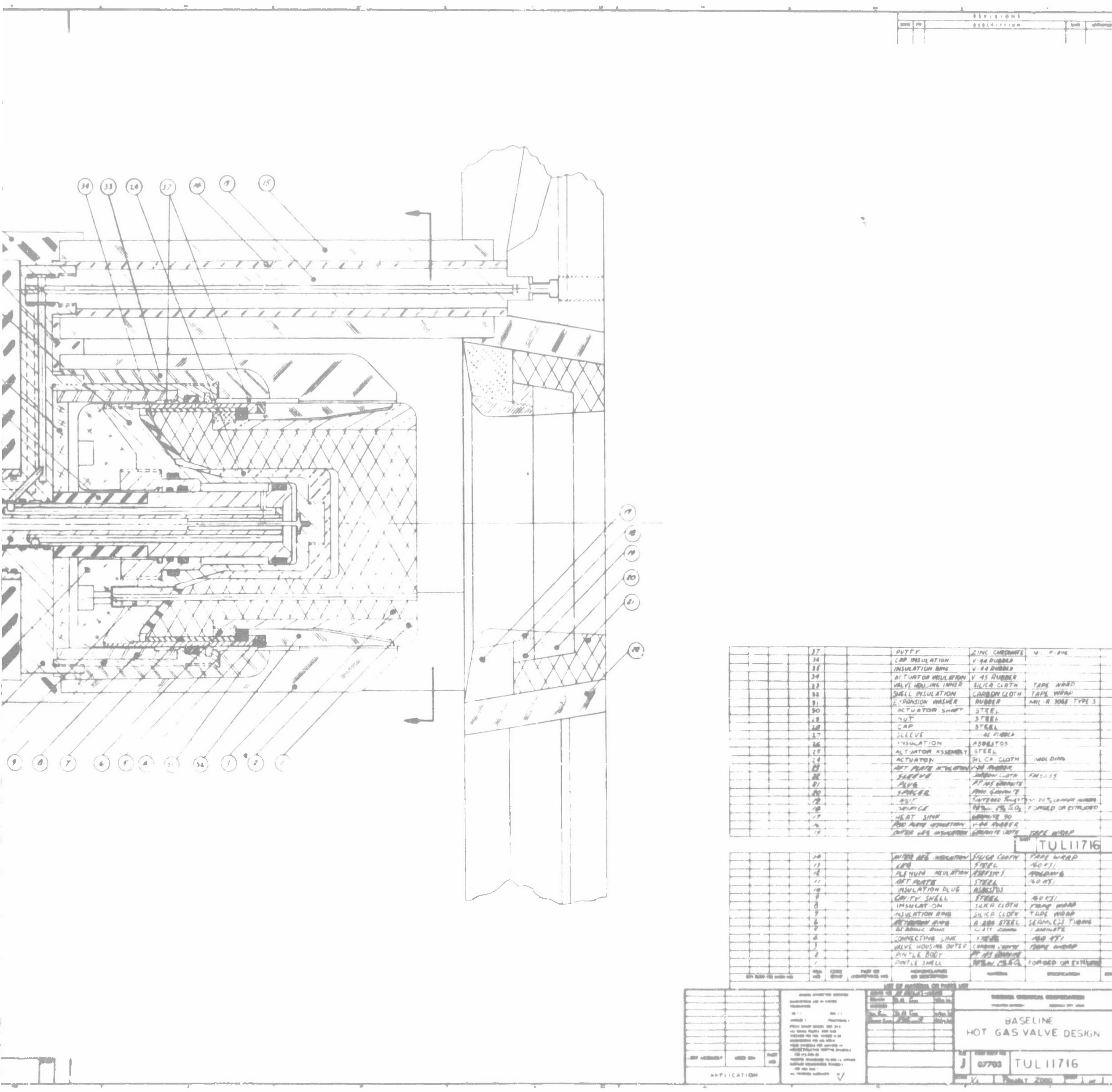


Figure 5. Baseline Hot Gas Valve Design

2

(2) Housing--A steel structural member (aft plate) that transmits the pressure loads on the valve to the nozzle via the support legs was selected for the fixed housing. The actuator piston attaches to this aft plate. External insulation protects the plate from the internal motor environment. The three valve legs are protected by composite carbon cloth and silica cloth phenolic tape wrapped sleeves. These legs are also used to route the hydraulic fluid and feedback electrical leads from the nozzle to the internal valve actuator. A steel cavity shell threaded to the aft plate provides the structural support for the pirtle housing. The cavity shell also contains a dynamic O-ring which seals on the pintle connecting link.

A composite silica and carbon cl a phenolic housing is used to protect the cavity shell, protect the movable pintle, and provide erosion resistance at the tip of the valve where the higher flows exist (Items 3 and 33, Figure 5).

(3) Actuator--This actuator uses a reverse design (piston stays stationary while the actuator housing moves) and has an internally mounted feedback transducer which provides proportioning capability to the system. The hydraulic fluid and feedback electrical leads are routed to the actuator through holes drilled in the submerged nozzle structure, valve legs, and valve housing structure. The hydraulic fluid flow is controlled by a standard servo valve mounted outside of the motor chamber.

This actuator was designed for use with either a 3,000 or 4,000 psi hydraulic system. The actuation parameters are listed below.

1.	Actuator Type	Reverse
2.	Hydraulic Fluid	MIL-H-5606
3.	Operating Pressure	4,000 psi (max.)
4.	Proof Pressure	6,000 psi
5.	Burst Pressure	10,000 psi
6.	Extend Area	4.88 sq in.
7.	Retract Area	1.77 sq in.
8.	Stroke	2.0 in.
9.	Cyclic Rate (full stroke)	0.5 cps
10.	Temperature Range	0 to 275°F

(4) Orifice--The valve orifice uses a tungsten insert (retained by its taper and a threaded retention ring) to eliminate erosion and provide a seating surface for the tungsten pintle shell. The tungsten insert is backed by a graphite support ring, and a pyrolytic washer is located just aft of the tungsten insert in the orifice to achieve a more gradual transition from the tungsten to the PTB graphite orifice liner. This washer also transmits the seating loads imposed on the insert to the other orifice members.

A carbon cloth cone thermally protects the steel nozzle components and transmits the loads imposed on the orifice to the nozzle structure. The PTB graphite and carbon cloth tape wrap extend into the nozzle exit cone to provide a material around the exit plane of the valve orifice, which has an erosion rate comparable to that of the nozzle exit cone materials.

(5) Valve Sizing--The program requires that a 0.07 side force ratio be demonstrated on the 120 in. demonstration motor. A side thrust ratio of 0.0724 based on sea level thrust must be demonstrated to achieve a thrust ratio of 0.07 after the test stand and data acquisition inaccuracies have been removed. This condition required the hot gas TVC system for the 120 in. motor be re-evaluated during the first quarter.

Equations developed by Thiokol under Contract AF 04(611)-9075 were used to predict the system performance. Available static test data were correlated with the theoretical predictions to estimate valve flow coefficients.

Force ratio (based on vacuum thrust) versus flow rate ratio curves were generated for various primary nozzle throat areas using the analytical performance model (Figure 6). Because of the small effect of nozzle throat size on system performance ($\pm$ 0.857 percent), one curve can be used to represent the system performance.

The vacuum force ratio data in Figure 6 were corrected to sea level conditions (Figure 7). Also shown in Figure 7 is a dashed curve which represents a 15 percent degradation in the predicted sea level performance.

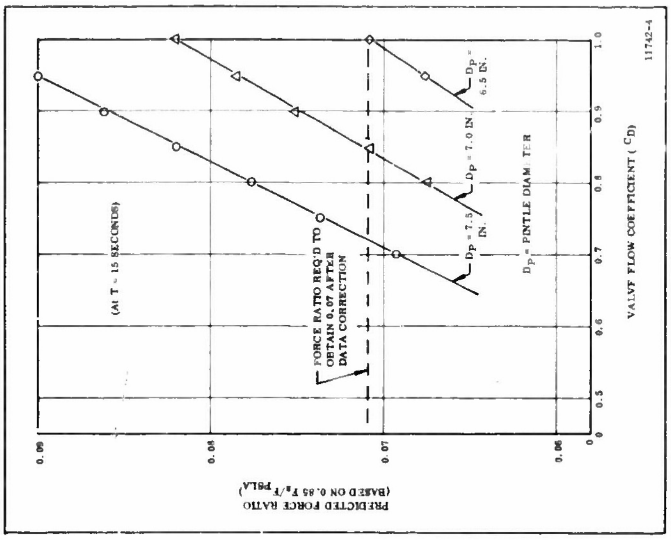


Figure 6. Force Ratio vs Flow Coefficient

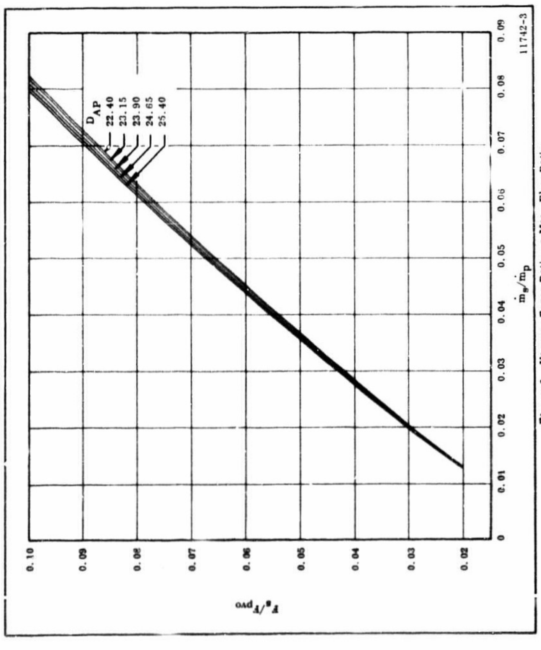


Figure 6. Vacuum Force Ratio vs Mass Flow Ratio For Various Primary Throat Diameters

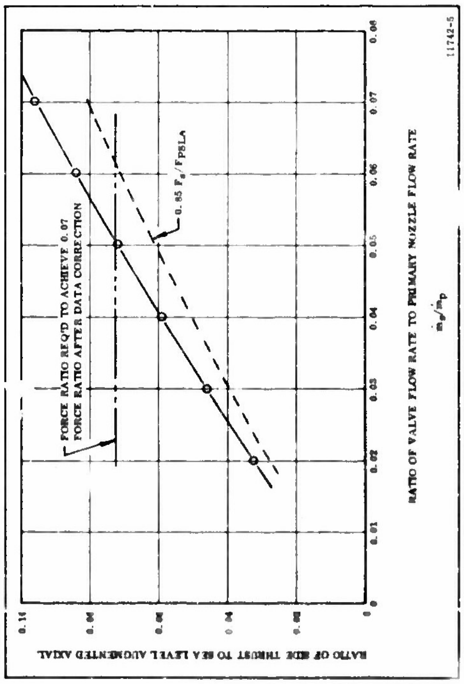


Figure 7. Force Ratio vs Flow Rate

Review of available test data indicated that actual system performance achieved with hot gas injection systems were 15 percent lower than that of the predicted performance. This modified curve represents the actual expected system performance.

The expected performance curve shown in Figure 7 was used to define the valve size. Since the valve size required was a function of the valve flow coefficient, force ratio curves as a function of flow coefficient for three pintle diameters were generated (Figure 8). It is apparent from this figure that a 6.5 in. diameter pintle is unsatisfactory because a flow coefficient greater than one would be required to achieve the required force ratio of 0.0724 (prior to data correction). Both the 7.0 and 7.5 in. diameters appear satisfactory if their respective valve flow coefficients can be attained. The valve flow coefficients obtained for small valves developed by Thiokol under Contract AF 04(694)-334, MINUTEMAN Production Support, and Contract AF 04(694)-774 were analyzed. These data indicated that flow coefficients exceeding 0.8 would be ve   ptimistic and that coefficients as low as 0.720 might be achieved with the large valve due to severe entrance flow conditions. Based on these considerations, the pintle size selected was 7.5 in. in diameter.

Figure 9 defines the predicted force ratio as a function of the demonstration motor operation time. This curve indicates the required force ratio will be achieved anytime the valve is fully open until 40 sec, which should provide ample time to demonstrate a 0.07 force ratio capability by all four valves during the system demonstration test.

The design analysis and calculations are discussed under A.3, Design of Pintle Valves for Test Motors.

11742-33

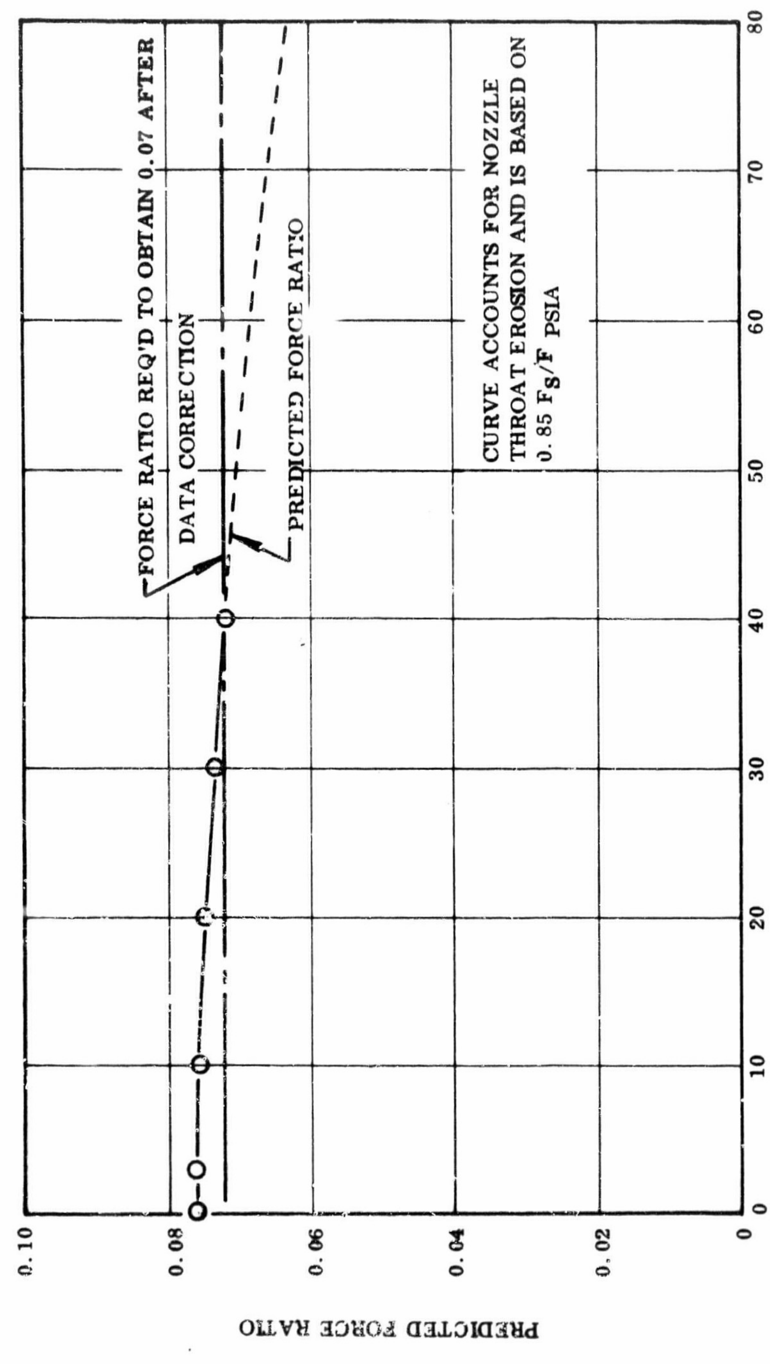


Figure 9. Predicted Force Ratio vs Time

2. DESIGN OF 65 INCH DIAMETER TEST MOTORS

A 65 in. diameter test motor (designated TU-521) was designed during this first quarter. The design was based on maximum utilization of existing subscale MINUTEMAN test hardware (modified TU-190).

The motor was designed to be capable of repeated testing (three tests) with two full scale hot gas pintle valves (156 in. diameter motor system). The mass discharge rate of the motor will be sufficient to provide full flow for one full scale test pintle valve.

The following criteria and requirements were used to design the first test motor (TU-521.01).

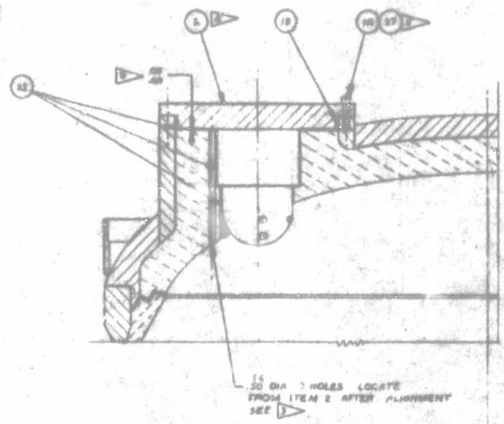
1. Firing Duration, 60 sec
2. Chamber Pressure, 700 psia (maintained with one valve full open and one valve closed)
3. Flame Temperature, 5,700°F

The test motor configuration is presented in Figure 10. The motor contains the three unique features listed below.

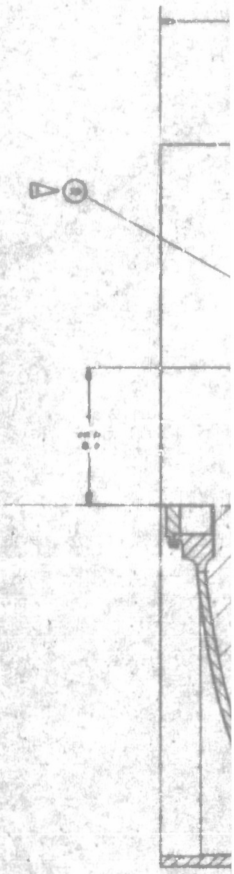
1. Two hot gas valve systems with external actuation.
2. Two plenum chambers for mounting the valves internally.
3. An auxiliary nozzle and burst diaphragm to vent excess propellant gases.

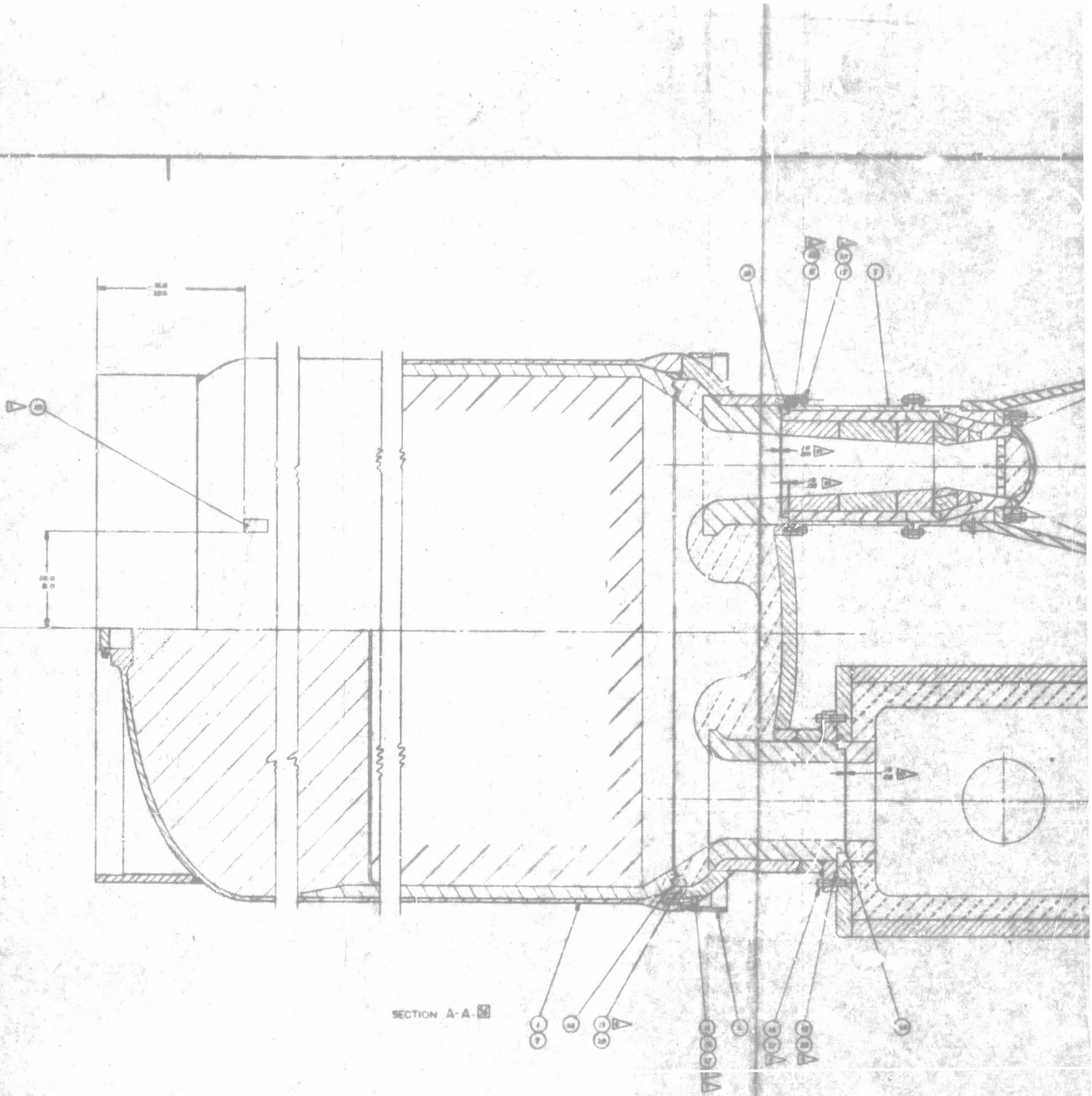
a. <u>Motor Performance and Ballistics</u>--The TU-521-01 motor will contain an end burning uncured propellant grain configuration. The propellant diameter is 62.25 in. which gives a propellant burning surface of 3,043 sq in. The web thickness is 31.50 inches.

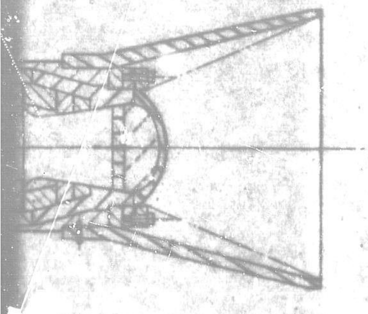
The propellant for the TU-521 motor designs, designated TP-H1113, is as follows.

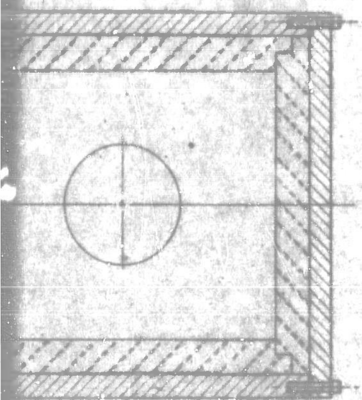


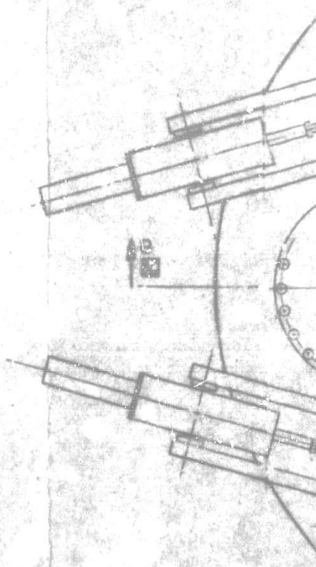
SECTION B-B



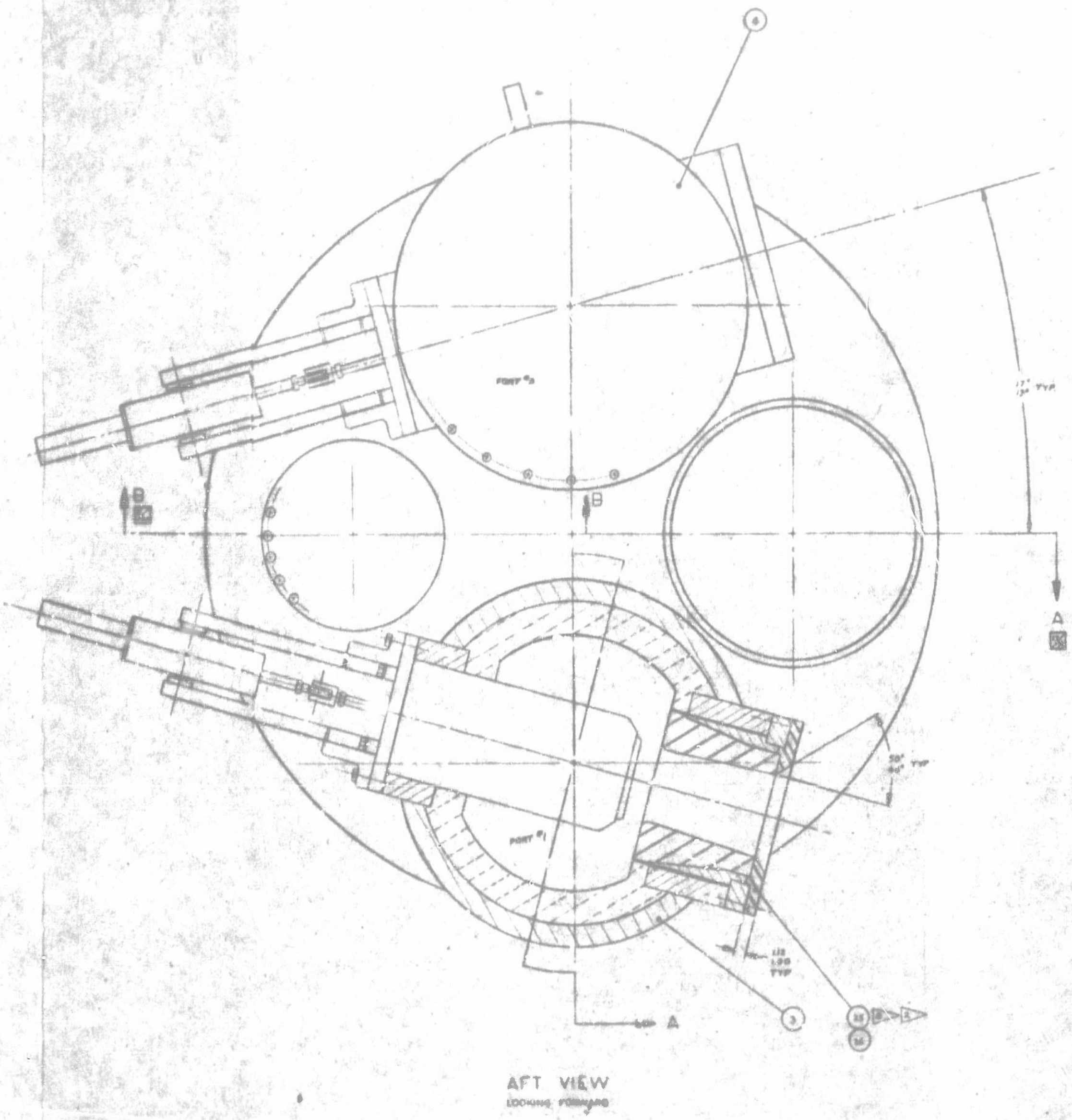

SECTION A-A







7U39974



7U39974

14

CONFIDENTIAL

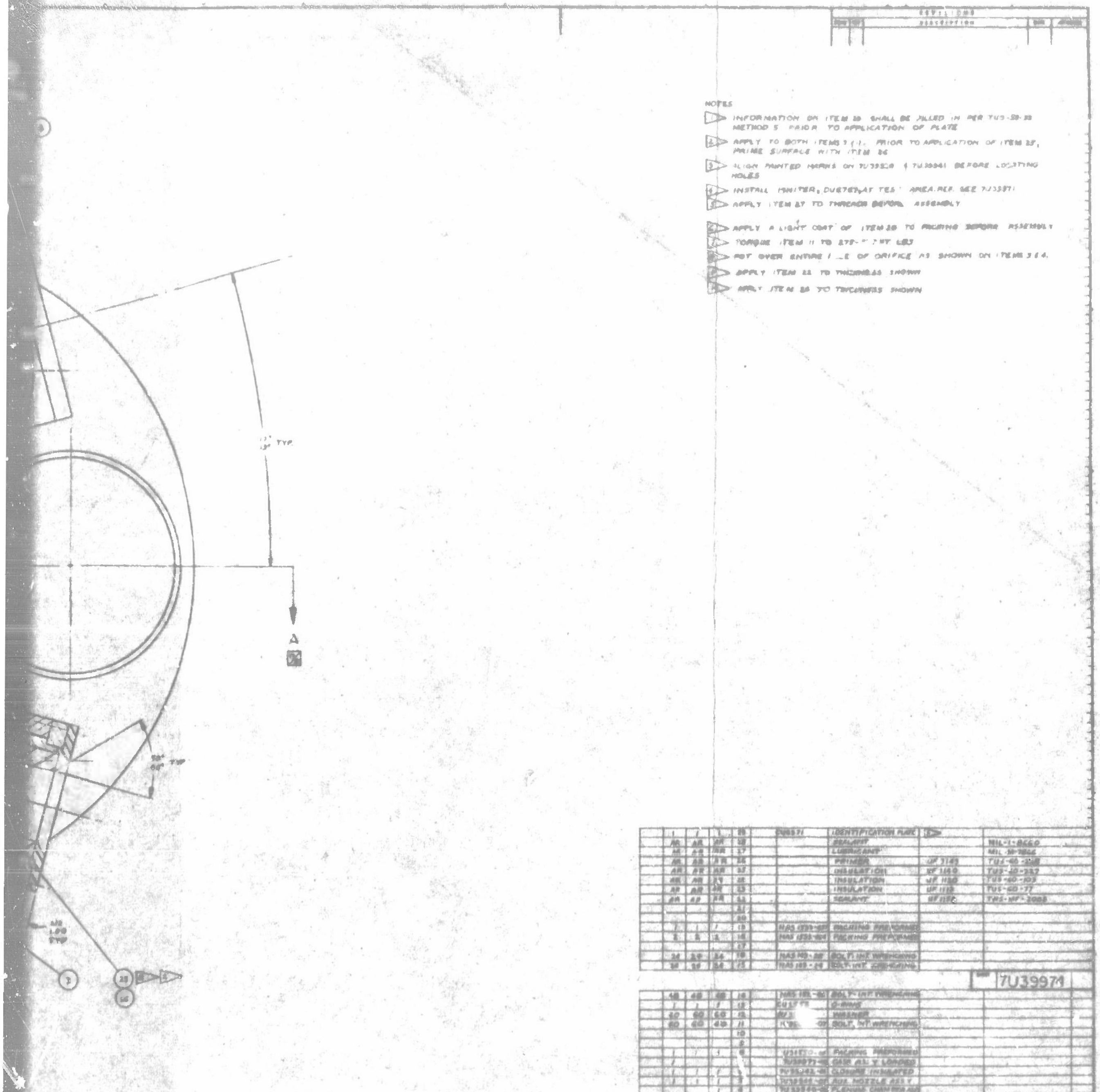


Figure 10. Test Motor Configuration

CONFIDENTIAL

5

Ingredient	Composition (% by wt)
HB Polymer	10.00
DOA	3.00
Aluminum	16.40
Fe_2O_3	0.60
Ammonium Perchlorate	70.00

The target burning rate for TP-H1113 propellant in the TU-521 motor is 0.526 in./sec at 700 psia and the characteristic velocity is 5,170 ft/sec. The burning rate exponent is 0.45, and the density is 0.064 lb/cu inch. The TU-521.01 motor propellant weight is 6,140 lb.

During the next quarter, ballistic performance parameters and a pressure versus time trace will be predicted for each motor based on its duty cycle.

b. Case Design--The available case (S/N 0000010, U8930-03) hardware for the TU-521.01 motor was subjected to a stress analysis to confirm its ability to withstand loads imposed during pintle valve demonstration testing. Based on several structural computer stress analyses, the results indicated the case can accommodate the anticipated loads. The margin of safety was 1.19.

c. Insulation Design--The case insulation design for the TU-521 motor is the basic, proven design used for numerous MINUTEMAN subscale motor tests. The material is UF-1140, an elastomeric asbestos filled epoxy polysulfide. The thickness requirements are identical to previously fired motors and are conservative. The factor of safety is greater than three. About 1.5 in. of material is applied uniformly along the case wall. Virtually no material loss is experienced.

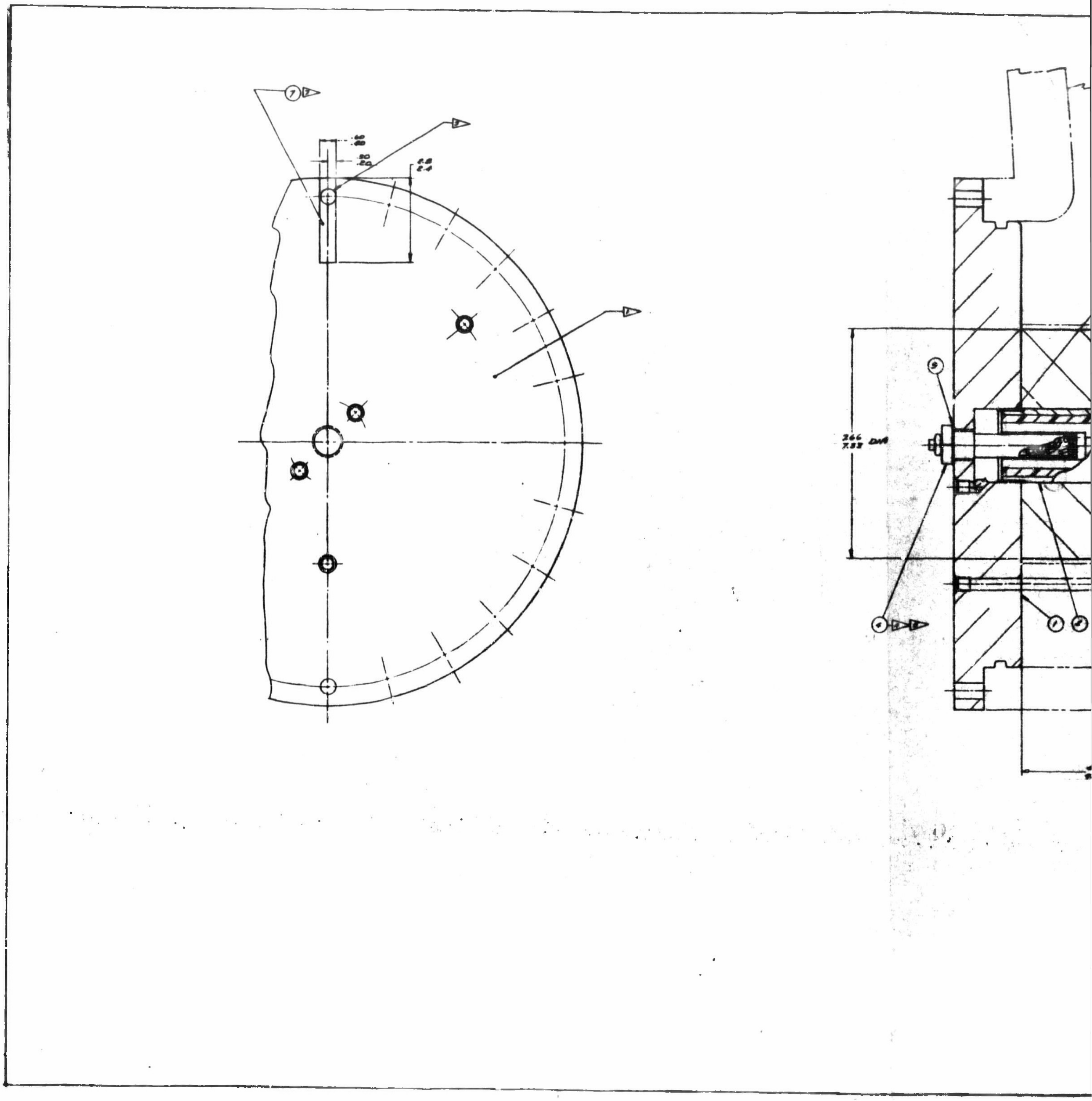
d. Igniter Design--A short length (7.35 in.) version of the TU-P140 MACE PYROGEN igniter was selected for the TU-521 motor tests. The MACE igniter grain is the same as that of the Stage I MINUTEMAN igniter and the propellant is faster burning than the MACE propellant.

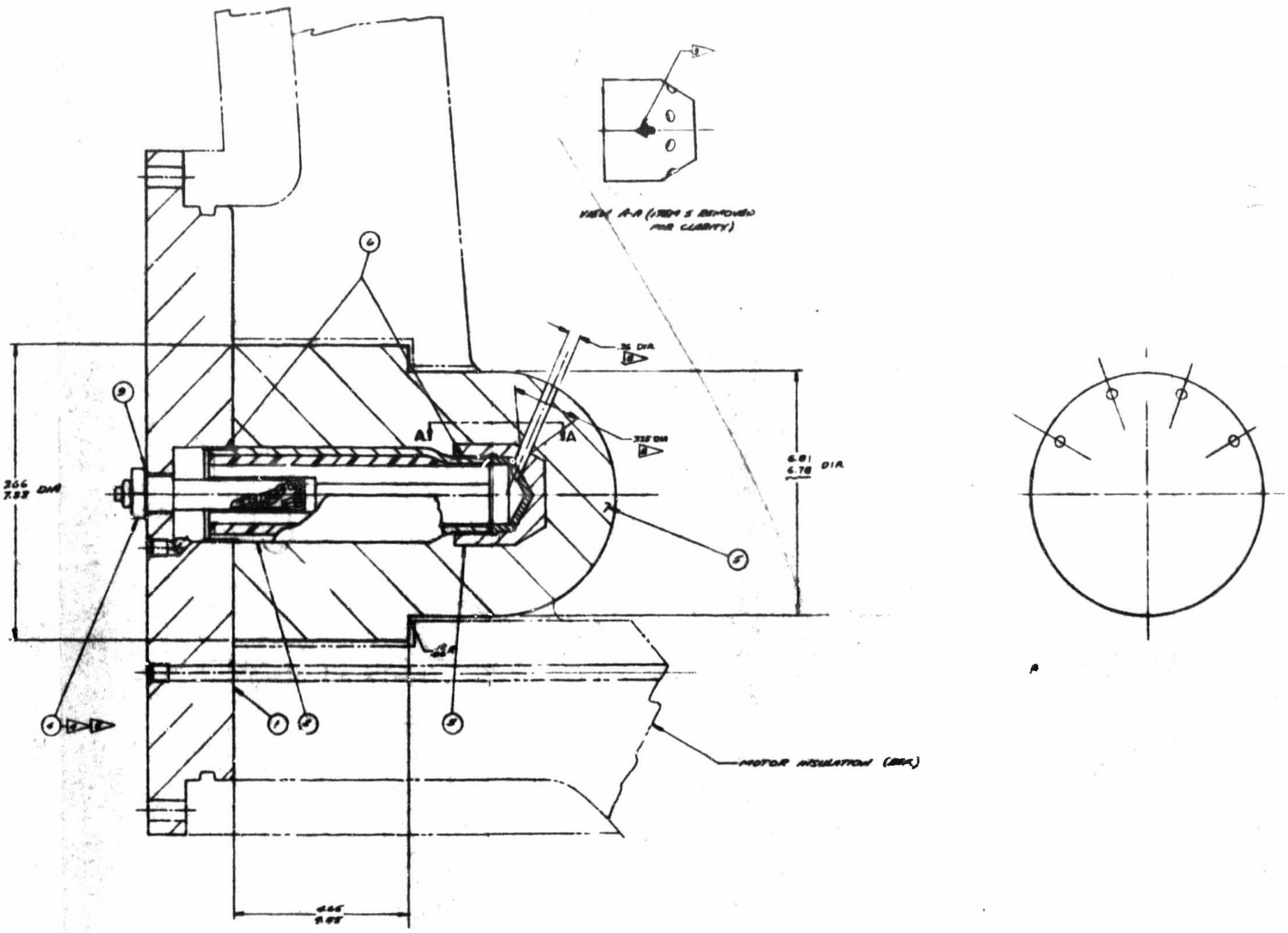
The loaded PYROGEN igniter (designated TU-521 igniter) will thread into an adapter plate which will be bolted to the aft closure port of the TU-521 motor. The igniter case has a four-port nozzle threaded to its aft end and is oriented and bonded in place during assembly to assure that the desired flame pattern is achieved. The nozzle is internally insulated to protect the bond line between the nozzle and its external insulation. The entire PYROGEN assembly is insulated with UF-1120, which completely covers the aft end of the igniter with 1.75 in. of insulation except for the exhaust holes, which are open. The remainder of the insulation is configured to fit into the motor aft closure insulation.

The PYROGEN igniter will be ignited by a booster initiator in which 20 gm of size 2A boron-potassium nitrate pyrotechnic pellets contained in a perforated fiberglass tube are initiated by an electric squib. The igniter design is shown in Figure 11, and the predicted performance is shown in Figure 12.

The maximum mass flow rate from the TU-521 igniter is 3.6 lb/sec. The mass flow from each igniter nozzle is 0.9 lb sec. Figure 13 shows the surfaces contacted by the four igniter plumes. A "worst case" may be considered by assuming a 15 deg half angle on the plume and that all the mass flow strikes the surface shown (through deflection off the aft closure and case wall). The smallest surface has an area of 260 sq inches. This amounts to an average mass impingement of 0.0035 lb/sec/sq in., indicating that the surface of the propellant in the TU-521 motor will not be seriously disrupted.

It may be necessary to open both valves upon ignition to avoid over pressurization induced by the extra surface. This condition was predicted using throat areas corresponding to both one and two valves open. These two predictions are presented in Figure 14. The rate of rise is gradual with a maximum $\frac{dP}{dt}$ of 2,537 psi/sec. The gradual rise is attributed to the large free volume rather than to the flame spreading rate since the total surface will be burning within 0.030 sec after first ignition. The only way that the rise rate could be increased would be to increase the igniter mass flow rate. This will be unnecessary because the predicted transient is satisfactory.





VIEW A-A (ITEM 5 REMOVED FOR CLARITY)
.36 DIA
.325 DIA
6.81
6.78 DIA
A
A
MOTOR INSULATION

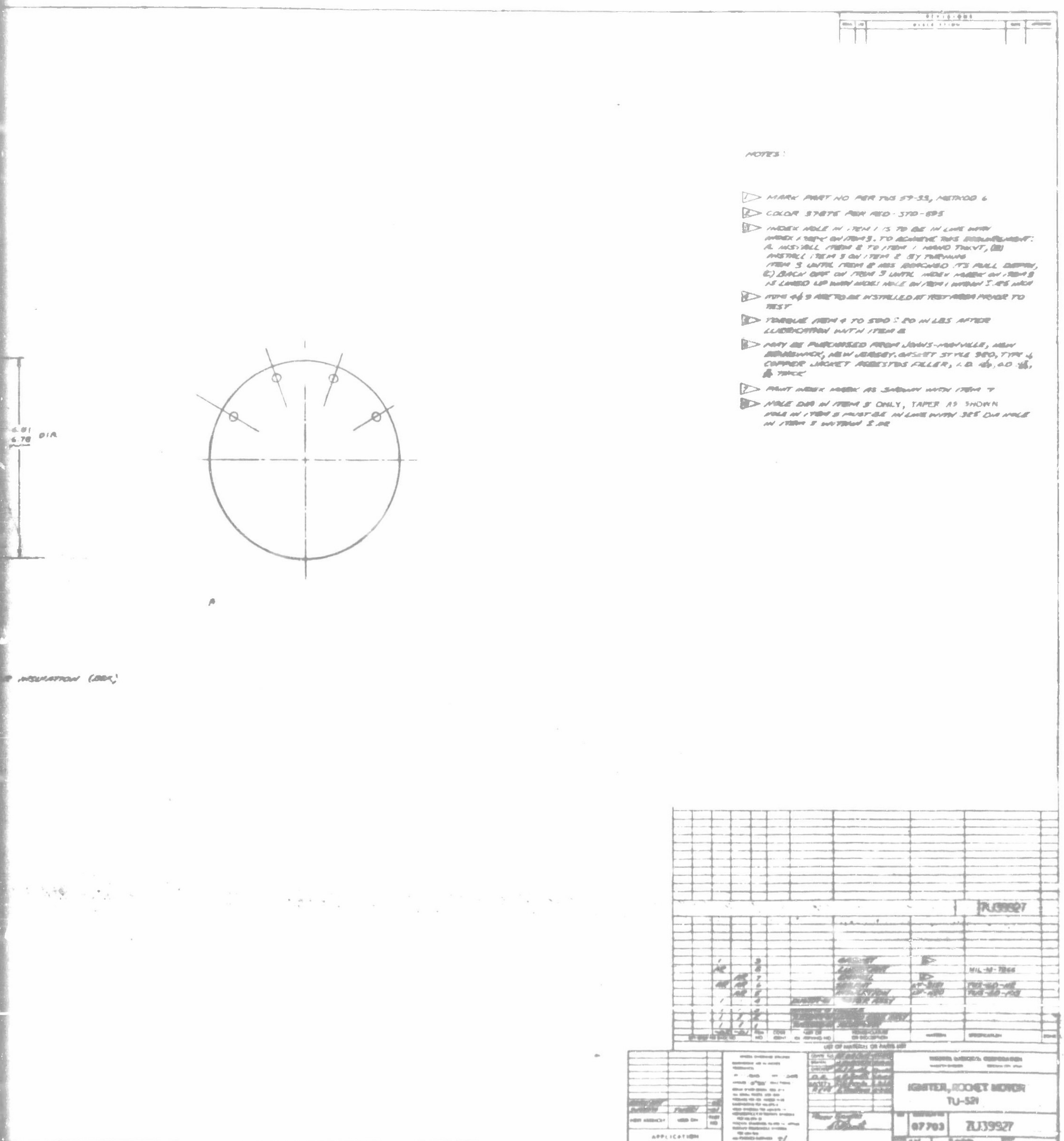


Figure 11. TU-521 PYROGEN Igniter Design

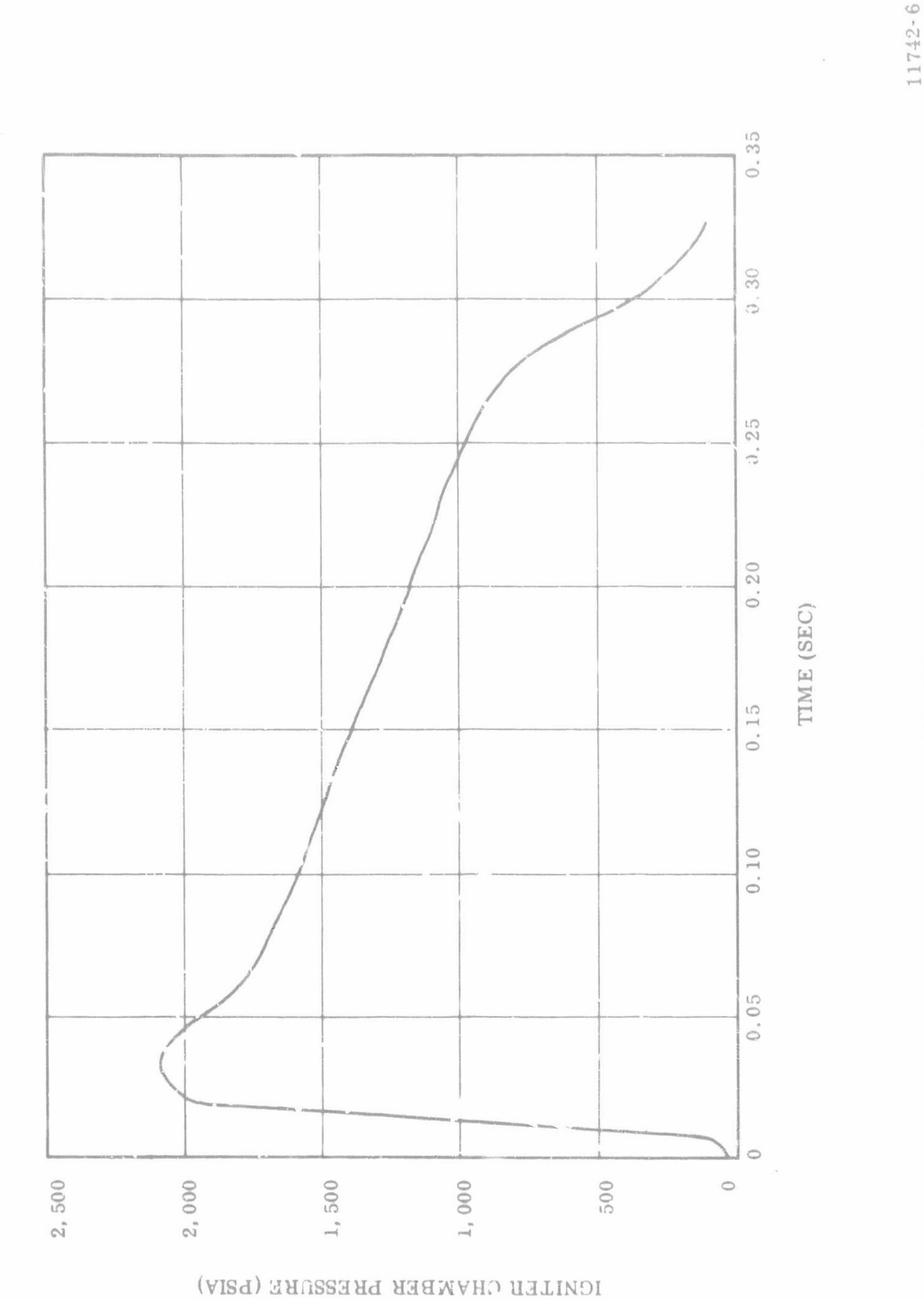


Figure 12. Predicted TU-521 Igniter Performance

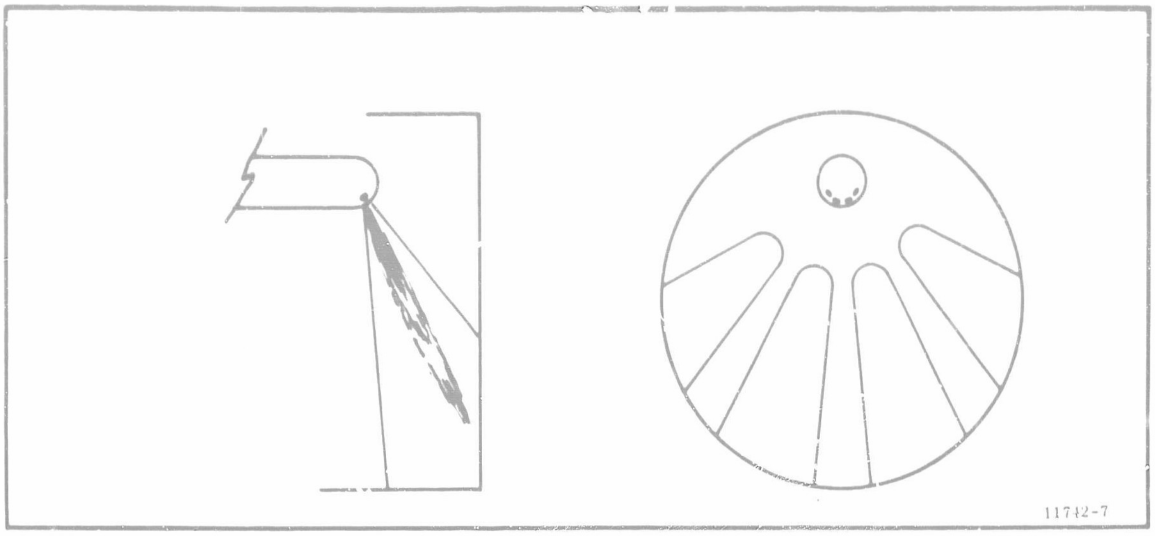


Figure 13. TU-521 Igniter-Flame Impingement Pattern

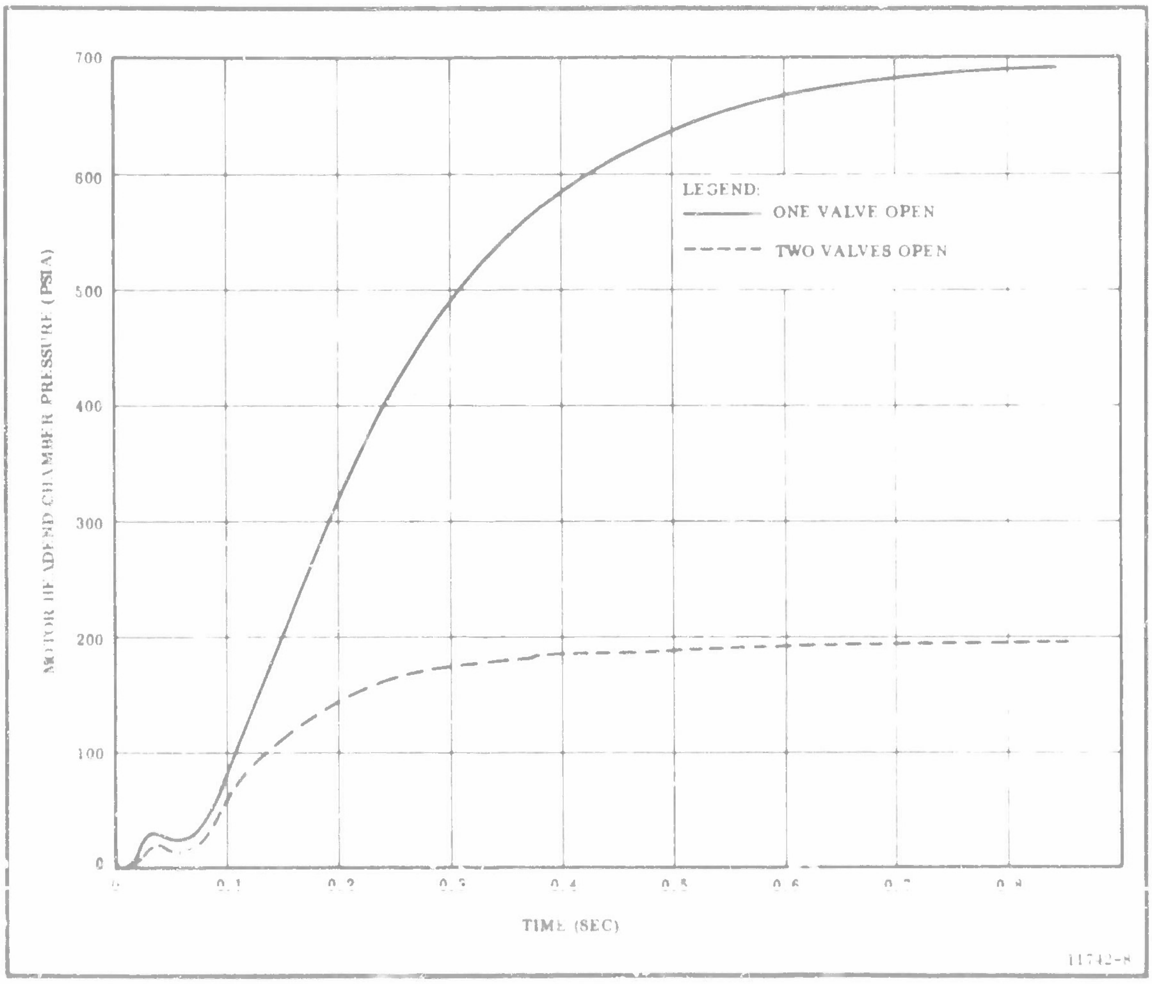


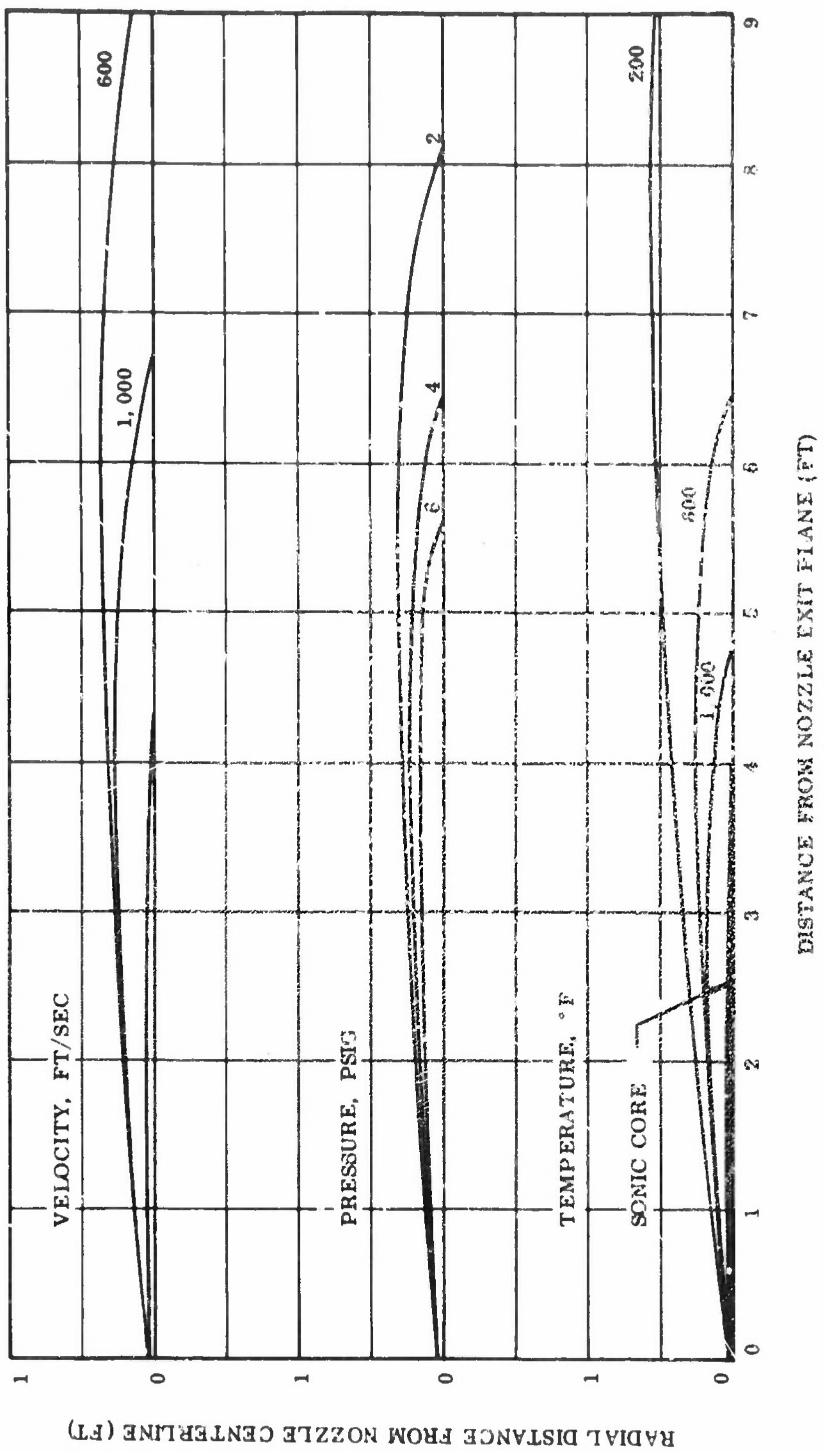
Figure 14. TU-521 Predicted Motor Ignition Transients with One and Two Valves Open

It is not considered necessary to open both valves at ignition although apparently it would not extend the time to achieve motor equilibrium pressure.

The TU-521 PYROGEN igniter has four nozzles. The centerline of each nozzle forms a 24 deg angle with the surface of the propellant and the igniter is externally insulated. Originally, it incorporated a 15 deg half angle expansion in each nozzle to produce a nozzle area ratio of 16:1.

The igniter exhaust plume was analyzed with an operational Thiokol computer program. The plume pressure, velocity, and temperature profiles were calculated as shown in Figure 15. These plots show the plume to have a long thin supersonic core. This high velocity core has the capability of eroding and dishing the uncured propellant. The static pressure against the propellant was calculated to be 120 psi where the supersonic plume impinges. This was too high a load to expect the uncured propellant in the TU-521 motor to withstand without deformation. Steps were therefore taken to assure that the flow becomes subsonic prior to impinging on the propellant surface. Plume length was directly proportional to the exit diameter where the exhaust leaves the nozzle. The nozzle exhaust holes through the insulation were redesigned to produce a 1.2 to 1.0 area ratio. This effectively shortened the length of the supersonic core to less than 1 ft (Figure 16).

The temperature profile, pressure, and velocity were reduced; however, these are dynamic temperatures of the flowing gas stream. As the gas impinges on the propellant surface, it will lose velocity and re-acquire temperature which will approach the combustion temperature of the propellant, reduced in proportion by the amount of air entrained in the plume and other energy loss factors. The plume will be hot enough to rapidly heat and ignite the propellant surface but will not have sufficient velocity to produce a static pressure at the point of impingement and cause significant deformation. The total static pressure on the propellant surface produced by the exhaust plume of this revised igniter design is only 5 psig. A pressure this low for the short duration that the igniter fires will not damage the propellant surface.



11742-9

Figure 15. Igniter Plume Characteristic for TU-321 Igniter with a 16:1 Area Ratio

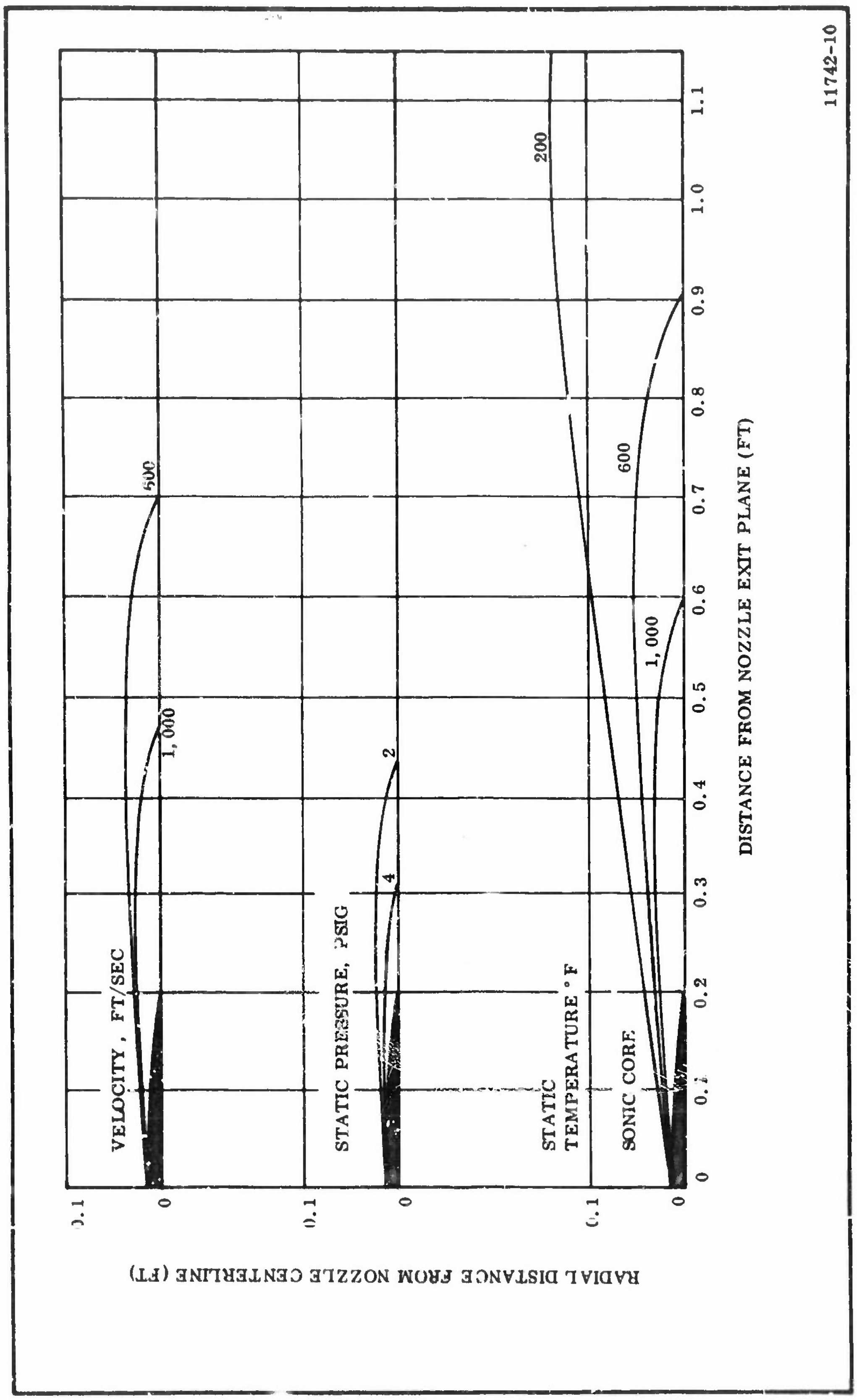


Figure 16. Igniter Plume Characteristic for TU-521 Igniter with a 1.2:1 Area Ratio

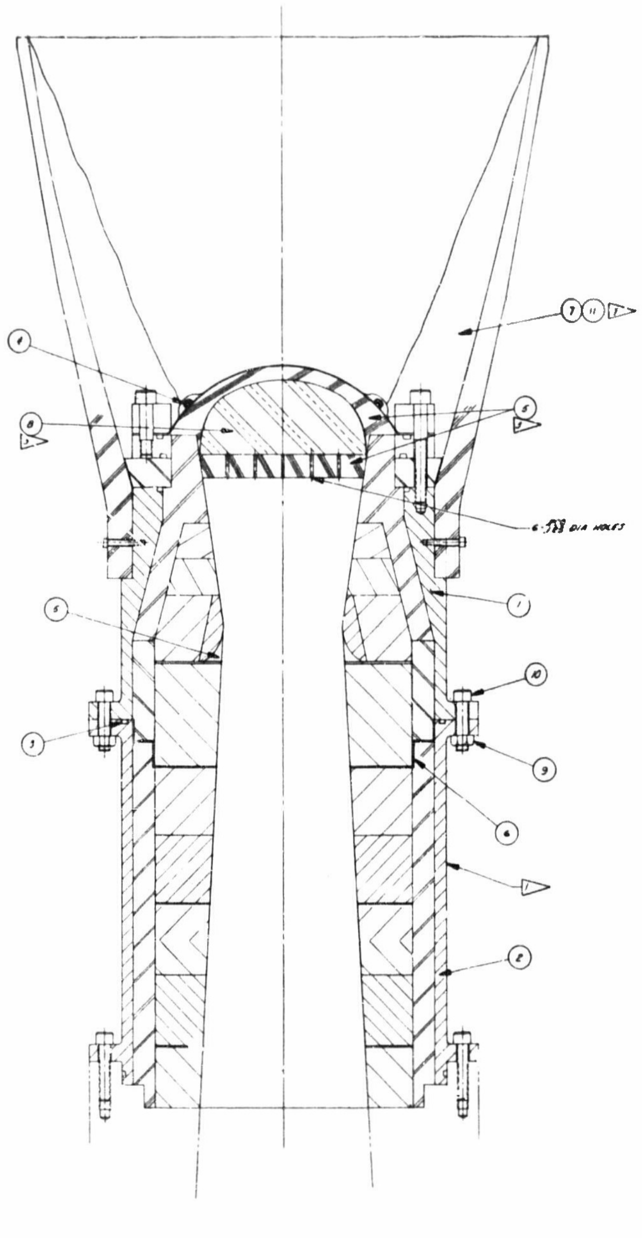
As soon as the motor is ignited, the chamber pressure will begin to rise. The increased pressure will have a depressing effect on the igniter plume, forcing the high velocity core back away from the propellant surface. At 150 m/sec after ignition of the igniter, the motor pressure will be 200 psi (see Figure 12). At this pressure, the plume will be forced completely back away from the propellant surface. The plume will not contribute to erosive burning of the motor propellant, and the igniter will unchoke completely before the motor pressure has reached equilibrium.

e. Auxiliary Nozzle and Burst Diaphragm Design--The auxiliary nozzle and burst disc assembly acts as a flow relief after the initial test period when full flow passes through the hot gas valves. If the valve malfunction should occur, the burst disc will rupture, thereby porting the motor and preventing a catastrophic failure so the valve hardware can be saved and analyzed. For normal operation, the burst disc will be blown at a predetermined time and the auxiliary nozzle will function as the primary flow channel for the motor gases.

Preliminary and final design and sizing of the auxiliary nozzle and burst disc assembly were made during this quarter. Structural and thermal analyses were also completed.

Conservatism was used in designing these components to provide more than adequate structural, thermal, and erosion margins of safety and to insure performance integrity of all components. At the same time, simplicity and economy of components and materials were carefully considered.

The nozzle and burst disc assembly is shown in Figure 17. The nozzle is a simple convergent-divergent design tailored to meet the flow and geometries of the TU-521 motor. The outer steel shell provides the necessary strength and attachment provisions and contains the insulative and ablative liners. The structural, insulative, and ablative components were sized to perform adequately over the full duration of the third test motor (120 sec firing time). The first two motor tests are of shorter duration (60 sec). This permits all three nozzles to be fabricated with a minimum



1

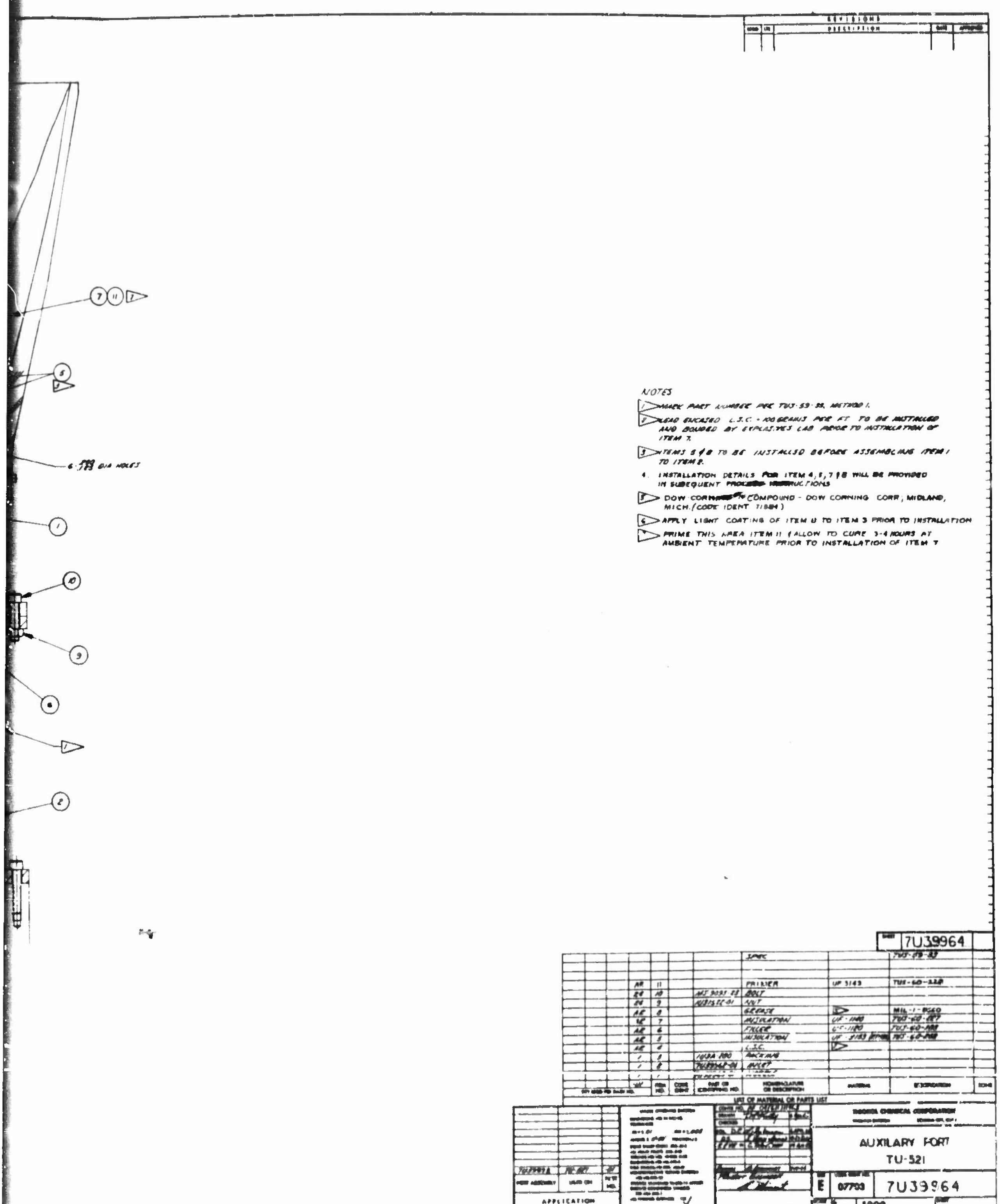


Figure 17. Nozzle and Burst Disc Assembly

of tooling and fixtures and may allow some of the components such as the inlet section steel from the short duration tests to be reused.

The throat and divergent section structure contains provisions for attaching the burst disc assembly and outer ablative and insulative shield. Surplus MINUTEMAN nozzle exit cones were adapted for this shield to reduce the length of the inlet and throat sections and to reduce the costs of the components. The unusual length of the total assembly was necessary to exhaust the hot gases from the motor downstream of the adjacent hot gas valve assemblies and prevent the components from being damaged.

The internal flow surfaces (except for the throat and aft divergent cone section) were formed by high density Graphite 90. This material was chosen because of its excellent erosion properties and resistance to thermal shock cracking.

Multiple ring construction was used to make the graphite assemblies. Past experience has shown that large unsymmetrical segments are more prone to cracking. In addition, this facilitates the installation of expansion washers for the relief of thermal stresses.

Tungsten was used as the nozzle throat because noneroding conditions are desired so flow and motor pressures will be affected only by and can be evaluated with respect to the hot gas valve modulations (duty cycle).

The outer cone shield was filled on the inside with UF-1140, an ambient curing thermal and erosion resistant material. Its primary purpose is to form a continuation of the divergent contour downstream of the burst disc so that the exhaust gases will not flare suddenly at this point after the burst disc is ruptured.

The burst disc assembly was designed and fabricated by Black, Sivalls, and Bryson to meet the configuration and requirements of the TU-521 motor. The burst disc was designed to rupture at 1,100 psi (+ 3% - 6%), which is below the pressure failure level of the test motor, so catastrophic failure and loss of valve hardware will not occur if the valve malfunctions. After the assembly is installed in the nozzle,

the disc will be insulated with RTV-88, the dished area filled with DC-4 grease, and this covered with a perforated disc of RTV-88.

The perforated RTV-88 disc and grease reservoir will act as a shock absorber for the burst disc during motor ignition to preclude any possibility of rupture under impact pressurization, even though the disc design strength is well above anticipated motor pressure levels.

A linear shaped charge bonded around the outer or downstream face of the burst disc completes the assembly. This disc cutting element is a 100 gm/ft lead encased LSC burning at a 2,500 ft/sec rate. It will be detonated at the completion of the hot gas valve full flow test sequence to open the auxiliary nozzle for full exhaust flow during the remaining motor burn time.

f. Plenum Chamber Design--The entrance to the plenum chamber was changed during this quarter from previous designs to reduce the high Mach flow. This was done by designing the entrance blast tube area to be symmetrical along the entrance centerline. To obtain a symmetrical flow straightener insert, it must extend inward beyond the nozzle-aft closure joint area. By protruding into the motor closure section, the gas flow velocities were reduced from Mach 1.0 to 0.54 along the inboard periphery of the inlet area to the plenum chamber. This high gas flow rate necessitates using a highly-erosive resistance material to insure successful operation for a 120 sec duration. The material proven in a similar application (i.e., blast tube inserts) was graphite; therefore, Graph-I-Tite G was specified throughout the plenum chamber inlet area. This material will experience very little or no erosion and with the silica and glass cloth phenolic-backing material, the steel structure will not experience any appreciable temperature rise.

The Graph-I-Tite G was segmented into rings and the backside outside diameter was tapered. The rings were segmented to relieve stress due to high temperatures and possible deflections in the inlet duct or flow straightener section. The tapered outer circumference will provide a means of locking or holding the insert from moving downstream into the plenum chamber. The erosive-resistance

materials and insulation backing materials are proven materials according to similar applications in numerous full scale and test motors.

The plenum chamber insulation material was changed from UF-1144 to TIH-704B (an asbestos and carbon black-filled HC polymer mastic material) because of possible spalling. Spalling often occurs in some areas under particular flow conditions, which could prevent the valve from operating. Such spalling of large pieces of insulation could lodge in the valve-port area.

Being a mastic type material, TIH-704B is more pliable and flexible in a cured state than UF-1144, thus spalling will not exist and erosive-resistance will be sufficient to withstand the expected flow in the chamber. The material must be applied using trowels and pneumatic hammers to obtain the desired configuration with minimum voids. The material will be applied in three layers to eliminate the possibilities of large voids extending to the steel housing. Previously measured material loss for similar operating conditions indicates the material will be adequate for this design application.

A detailed structural analysis was conducted to determine the shell thickness and configuration required to meet the structural loads. A shell thickness of 1.9 in. and a configuration as shown in Figure 10 were required.

3. DESIGN OF PINTLE VALVES FOR TEST MOTORS

The HGSITVC system design for the 156 in. full scale motor was used as a baseline for designing the Phase I test pintle valves. Layouts were prepared to evaluate envelope, interface, and assembly compatibility with the plenum chamber and external actuation. In addition, tolerances and interface assembly techniques were defined.

A preliminary design analysis was conducted on the 120 in. diameter motor design to insure compatibility of the Phase I test pintle valves with the 120 in. nozzle and motor design.

Based on the results of the compatibility analysis and evaluation of the individual 65 in. diameter motor design and duty cycle, the final design requirements for the Phase I test pintle valves were completed.

a. <u>TU-521.01 Valve Duty Cycles</u>--Duty cycles for the two HGSITVC valves to be tested on the TU-521.01 motor are described in Figure 18 and Table II. The duty cycles were developed to meet the following program objectives.

1. Verify valve and orifice survivability.
2. Determine valve and orifice gas leakage.
3. Obtain data on pressure balancing technique.
4. Determine open and close actuation forces.
5. Obtain pressure and temperature data from the pintle valve and orifice assemblies.

To satisfy the primary objective during the 60 sec TU-521.01 test, the first valve will flow a total of 500 to 600 lb of gas, and the second valve will flow 800 to 1,000 lb of gas. These amounts represent approximately one-fourth and one-half the mass flow requirements for flow through a valve on a 120 sec full scale test. The estimated flows through valves no. 1 and 2, as shown in Figure 18 are 534.3 lb and 905.2 lb, respectively. These mass flows were

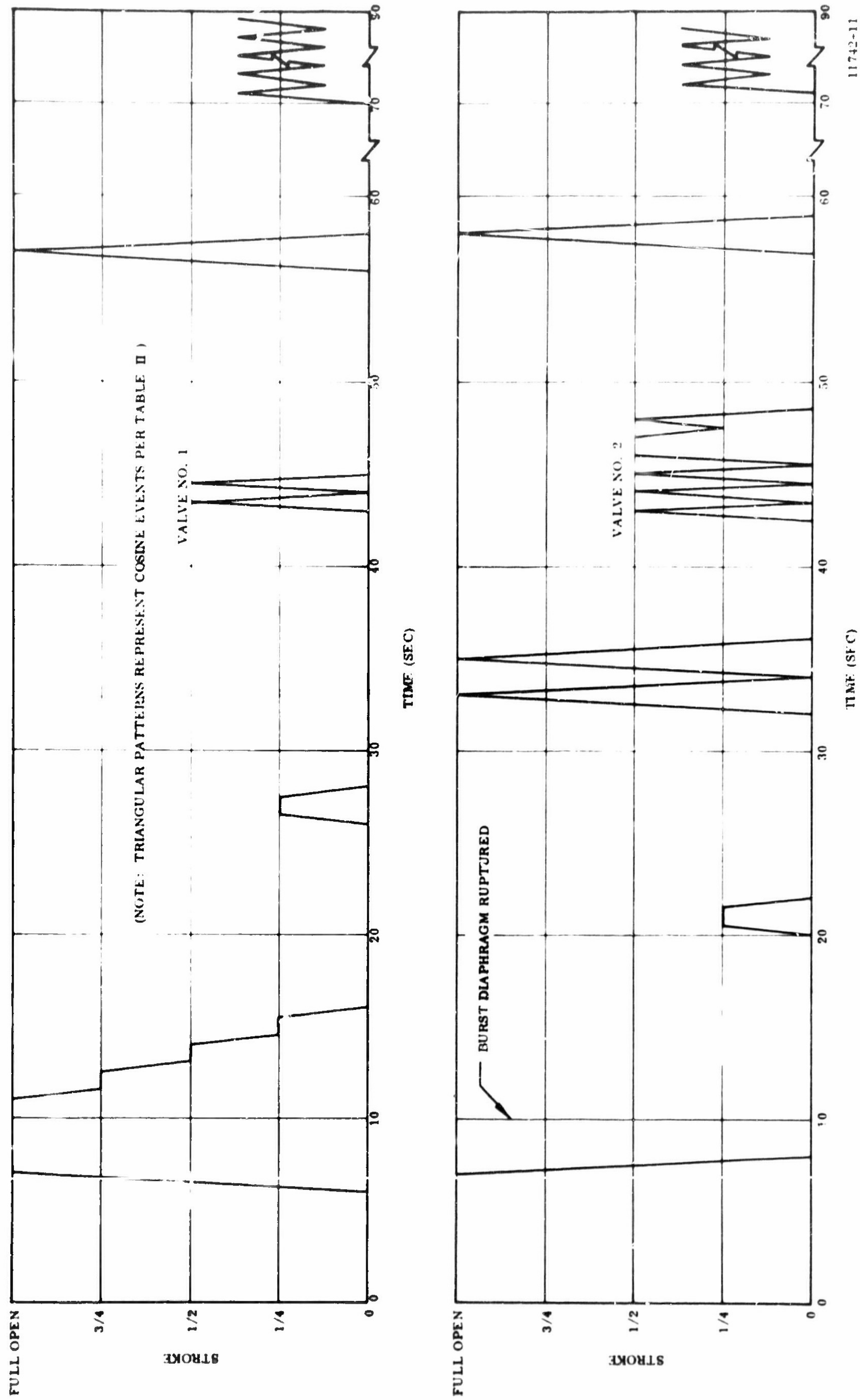


Figure 18. TU-521.01 Valve Duty Cycles

TABLE II

TU-521.01 DUTY CYCLE FOR VALVE NO. 1 AND 2

Event No.	Time (sec) From	Time (sec) To	Valve No. 1 Valve Position (in.)	Valve No. 1 Actuation Frequency (cps)	Valve No. 1 Wave Form	Valve No. 2 Valve Position (in.)	Valve No. 2 Actuation Frequency (cps)	Valve No. 2 Wave Form
1	-5.0	6.0	0.000	--	Hold	1.75	--	Hold
2	6.0	7.0	0 to 1.75	0.5	Ramp	1.75	--	Hold
3	7.0	8.0	1.75	--	Hold	1.75 to 0	0.5	Ramp
4	8.0	10.0	1.75	--	Hold	0.00	--	Hold
5*	10.0	11.0	1.75	--	Hold	0.00	--	Hold
6	11.0	11.5	1.75 to 1.3125	1.0	Transition	0.00	--	Hold
7	11.5	12.5	1.3125	--	Hold	0.00	--	Hold
8	12.5	13.0	1.3125 to 0.875	1.0	Transition	0.00	--	Hold
9	13.0	14.0	0.875	--	Hold	0.00	--	Hold
10	14.0	14.5	0.875 to 0.4375	1.0	Transition	0.00	--	Hold
11	14.5	15.5	0.4375	--	Hold	0.00	--	Hold
12	15.5	16.0	0.4375 to 0.00	1.0	Transition	0.00	--	Hold
13	16.0	20.0	0.00	--	Hold	0.00	--	Hold
14	20.0	20.5	0.00	--	Hold	0.00 to 0.4375	1.0	Transition
15	20.5	21.5	0.00	--	Hold	0.4375	--	Hold
16	21.5	22.0	0.00	--	Hold	0.4375 to 0.00	1.0	Transition
17	22.0	26.0	0.00	--	Hold	0.00	--	Hold
18	26.0	26.5	0 to 0.4375	--	Transition	0.00	--	Hold
19	26.5	27.5	0.4375	--	Hold	0.00	--	Hold
20	27.5	28.0	0.4375 to 0.00	1.0	Transition	0.00	--	Hold
21	28.0	32.0	0.00	--	Hold	0.00	--	Hold
22	32.0	36.0	0.00	--	Hold	0.875 ± 0.875	0.5	Cosine
23	36.0	42.5	0.00	--	Hold	0.00	--	Hold
24	42.5	43.0	0.00	--	Hold	0.00 to 0.875	1.0	Cosine Transition
25	43.0	45.0	0.4375 + 0.4375	1.0	Cosine	0.4375 ± 0.4375	1.0	Cosine
26	45.0	46.0	0.00	--	Hold	0.4375 ± 0.4375	1.0	Cosine
27	46.0	47.0	0.00	--	Hold	0.875	--	Hold
28	47.0	48.0	0.00	--	Hold	0.65625 ± 0.21875	1.0	Cosine
29	48.0	48.5	0.00	--	Hold	0.875 to 0.00	1.0	Cosine Transition
30	48.5	56.0	0.00	--	Hold	0.00	--	Hold
31	56.0	57.0	0.00 to 1.75	0.5	Cosine Transition	0.00	--	Hold
32	57.0	58.0	1.75 to 0.00	0.5	Cosine Transition	0.00 to 1.75	0.5	Cosine Transition
33	58.0	59.0	0.00	--	Hold	1.75 to 0.00	0.5	Cosine Transition
34	59.0	80.0	0.00	--	Hold	0.00	--	Hold
35	70.0	70.5	0.00 to 0.65625	1.0	Cosine Transition	0.00	--	Hold
36	70.5	71.0	0.65625 to 0.21865	1.0	Cosine Transition	0.00 to 0.65625	1.0	Cosine Transition
37	71.0	89.0	0.4375 ± 0.21875	1.0	Cosine	0.4375 ± 0.21875	1.0	Cosine
38	89.0	89.5	0.21875 to 0.65625	1.0	Cosine Transition	0.65625	--	Hold
39	89.5	--	0.65625	--	Hold	0.65625	--	Hold

*Third channel must show position change to activate burst disc.

calculated using n estimated discharge coefficient (C_d) 0.9 times the C_d calculated for the PSP hot gas seating valve (Figure 19). The value of 0.9 C_d was selected for the TU-521.01 valve because of an expected reduction in C_d resulting from differences in the TU-521.01 valve housing and valve orifice compared with the PSP seating valve housing and orifice (Ref TWR-1848).

Using the 0.9 C_d curve from Figure 19 and a curve of the TU-521.01 valve flow area versus stroke from Figure 20, a curve of valve C_d versus stroke was established (Figure 21). Combining Figures 20 and 21, an estimated valve predicted aerodynamic flow area versus stroke was obtained (Figure 22). The mass flow rate through the valve can then be determined using the data in Figure 22 and the pressure versus area relationship for the motor given in Figure 23 in conjunction with the following equation:

$$m = \frac{(A_{eff})\ (P)\ (g_c)}{C^*}$$

The mass flow through the valve prior to and following burst diaphragm rupturing as a function of stroke is shown as Figure 24. The mass flow increased approximately linearly with valve stroke up to a stroke of 0.5 in. open but with increasing stroke beyond 0.5 in., the mass flow increase with stroke was reduced. This resulted because of the large variation in chamber pressure with effective exhaust area, as shown by Figure 23.

The estimated mass flow through one valve at the full open position, before burst diaphragm rupture, was 97.28 lb/sec. This was more than three times larger than the mass flow after burst diaphragm operation which is 30.5 lb/sec at the full open position. The chamber pressure for the motor before burst diaphragm operation with one valve full open and the other closed was estimated to be 620 psia. This pressure could be higher because of thermal expansions which tend to close the valve opening and also if the C_d were lower than the estimated value. A closer estimate of the motor operating characteristics can be made on subsequent tests after this motor is tested. The time when the burst diaphragm is scheduled to be burst on the TU-521.01 test is 10 sec after motor ignition, as shown on Figure 18. This will give 8.0 sec of

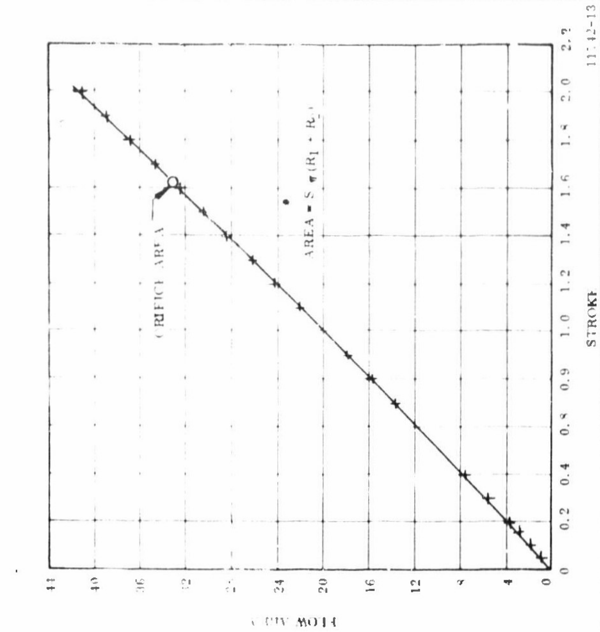


Figure 20. Valve Flow Area vs Stroke

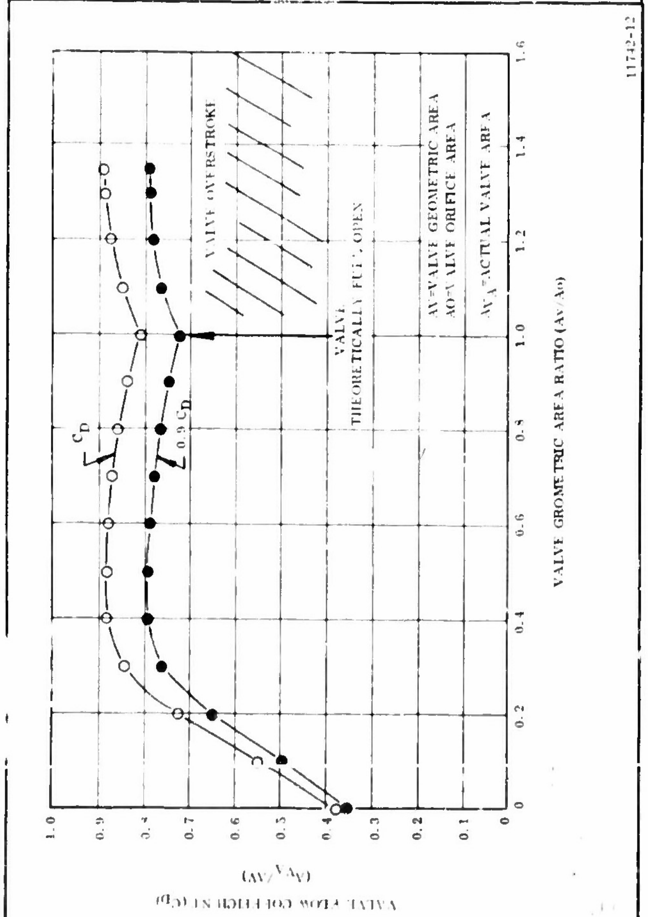


Figure 19. Valve Flow Coefficient vs Area Ratio

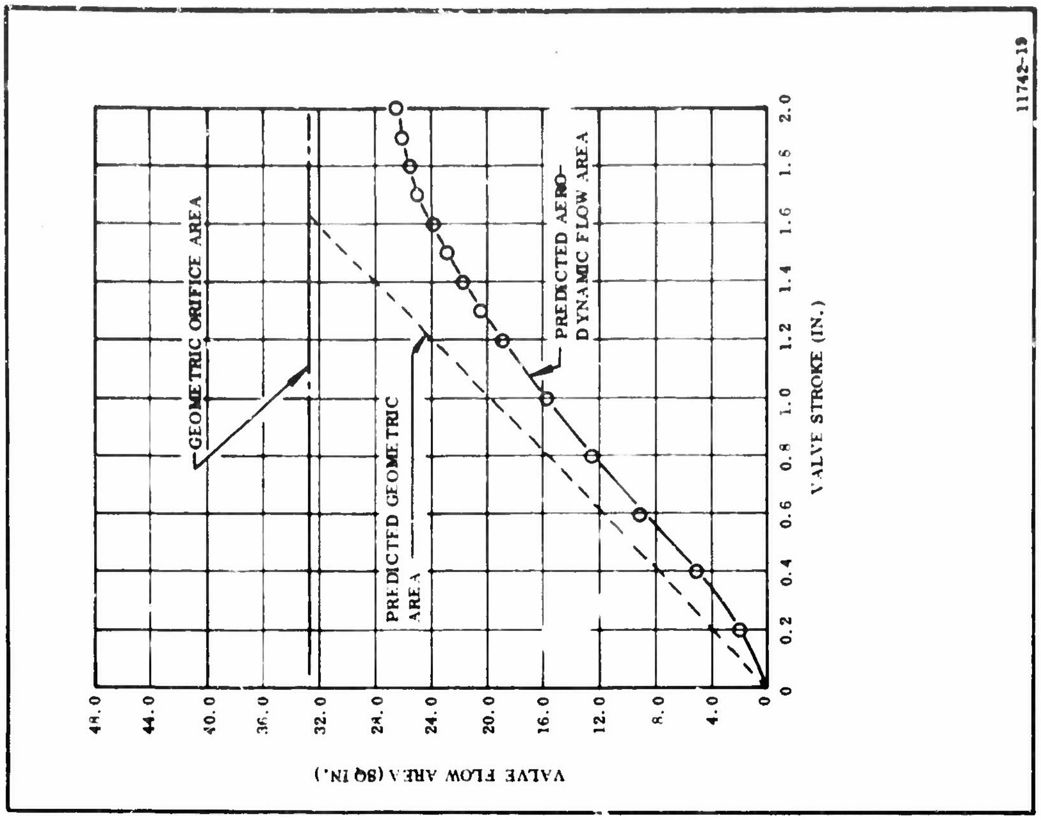


Figure 22. Valve Flow Area vs Stroke

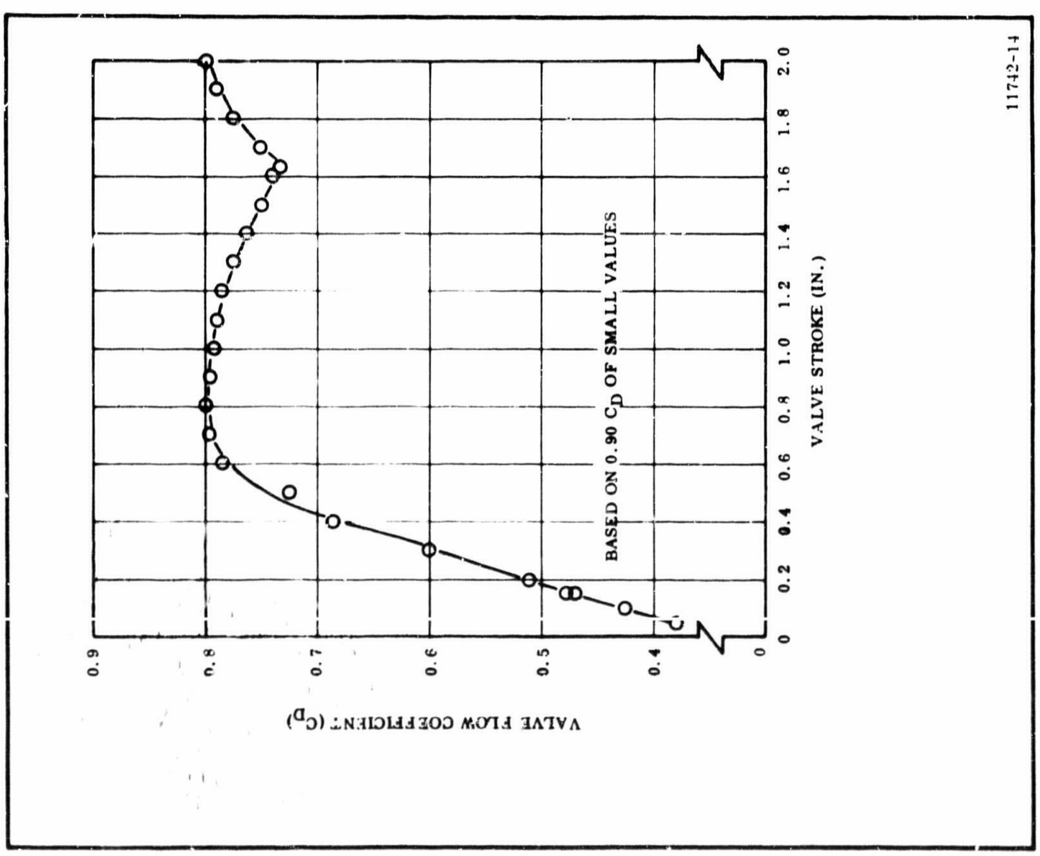


Figure 21. Flow Coefficient vs Stroke

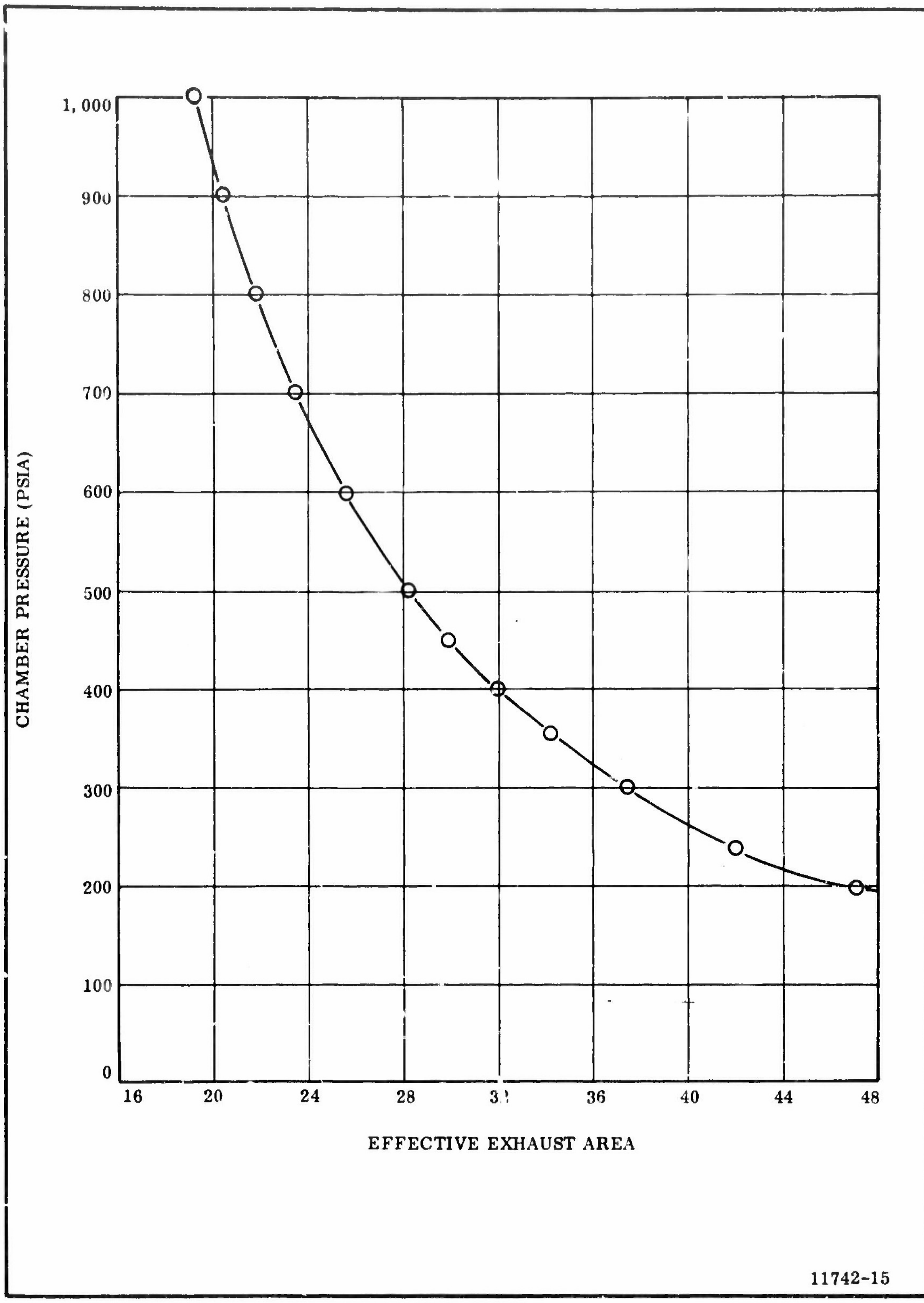


Figure 23. TJ-521.01 Pressure Variation

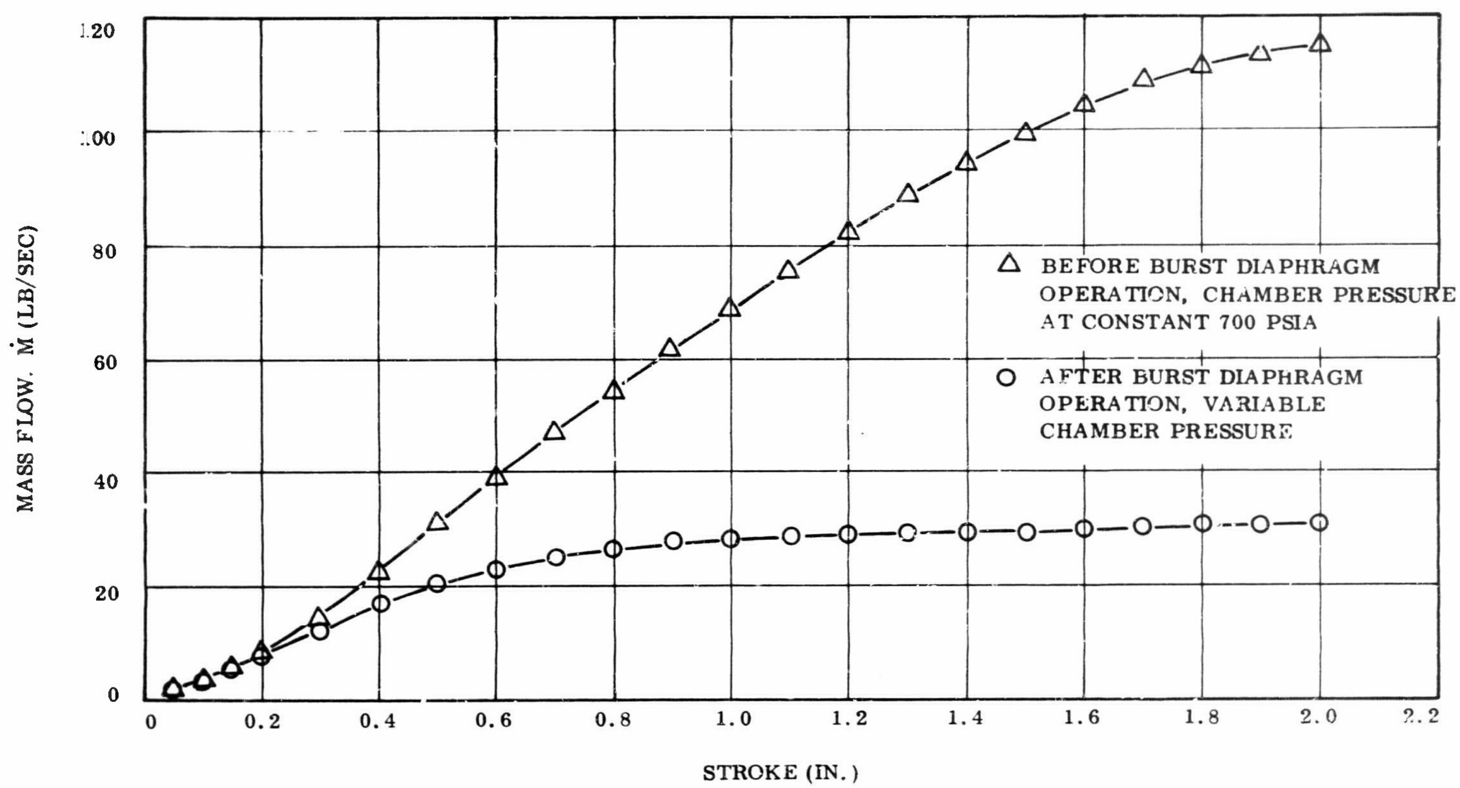


Figure 24. TU-521.01 Single Valve Mass Discharge Rate vs Stroke

high pressure flow through one or the other of the two valves. The other 2.0 sec will be at a reduced pressure because of both valves being open at the same time.

To determine valve leakage, the duty cycles of Figure 18 allow for five periods of 4 sec or longer when both valves are closed. An unobstructed camera view of the valve orifices will be possible at this time and a determination of the valve leakage can be made.

The duty cycles in Figure 18 have 1 sec holds at stroke positions of 1/4, 1/2, 3/4, and full open during some actuation events so the motor pressure can stabilize and the efficiency of the pressure balancing can be determined. Based on free volume calculations and previous PSP seating valve test data, a 1 sec hold time will be sufficient for chamber pressure to stabilize. Valve No. 1 has two holds at 1/4 open so the effect of test duration on pressure balancing can be judged. Valve No. 2 has holds at full open, 1/4 open, and 1/2 open which can be compared with similar holds on valve No. 1. The delay in pressure balancing can be determined from the cyclic events in each valve's duty cycle by comparing the measured pressure balance cavity pressure versus time with actuator position versus time.

Valve opening and closing forces, which are a function of valve friction, pressure balancing efficiency, and chamber pressure variations, can be determined with a minimized chamber pressure variation by opening one valve when closing the other. This type of valve operation is done with the two valves at 43 sec after motor ignition with each valve cycling between 1/2 open and closed out of phase with each other. This type of valve operation is also done at 57 sec after motor ignition when valve No. 2 is opened as valve No. 1 is closed.

b. <u>Design of Pintle Valves No. 1 and 2</u>--Three valve component tests will be conducted during the second, third, and fourth quarters of this contract to verify the structural integrity of the selected valve designs under progressively more severe operating conditions. Each test will evaluate two valves.

All design work for the first component test was completed this quarter. The design of the test hardware for the second test was initiated during this quarter.

(1) First Component Test (TU-521.01)--The first test will evaluate the critical pintle and orifice components. A modified pintle assembly (Figure 25) which will be bolted to a boss in the wall of the plenum rather than from three legs as shown in Figure 11. The orifice will be mounted in a similar boss directly opposite the pintle assembly.

This mounting technique was selected to use an externally mounted facility actuator. This configuration allows the critical valve and orifice components to be demonstrated and will provide design data for the next component test, which will employ leg mounting.

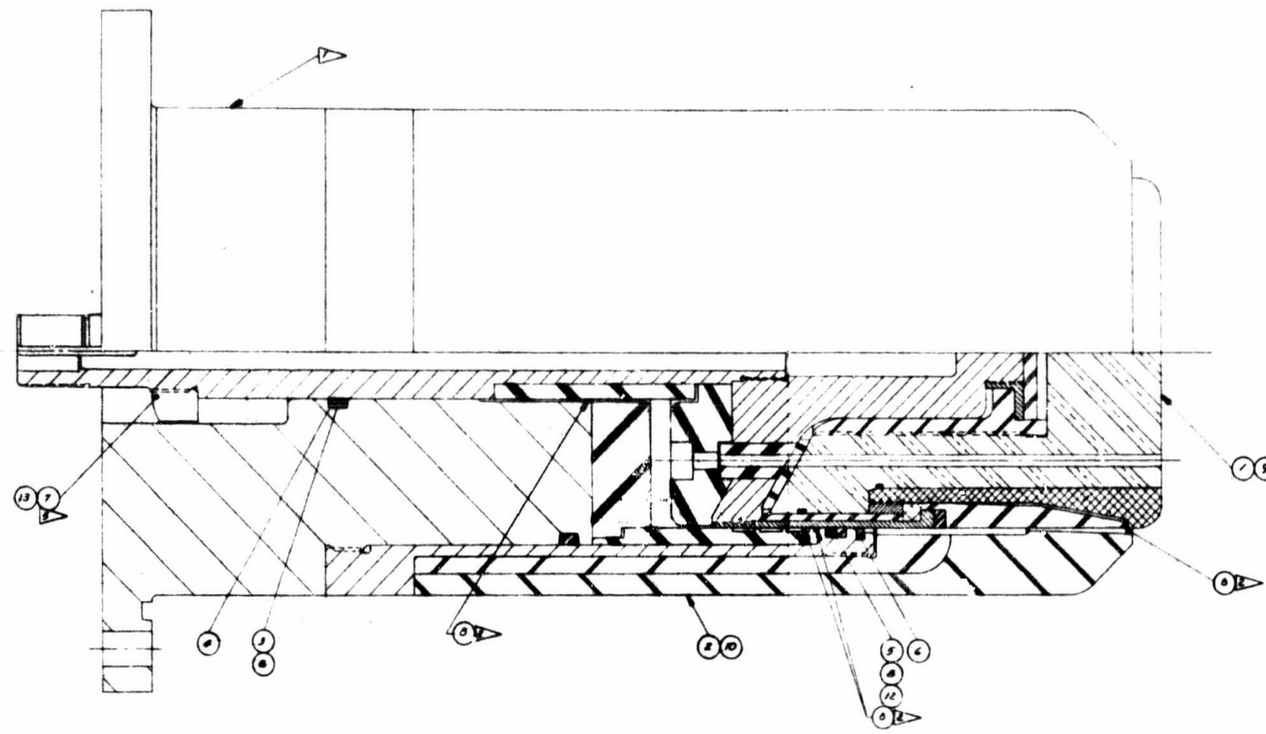
(a) Actuation System--Existing servo controlled actuators will be used to actuate the valves in this test. These actuators have the following operating characteristics.

Type	Facility
Fluid	MIL-H-5606
Operating Pressure	3, 000 psi
Extend Area	4.13 sq in.
Retract Area	4.13 sq in.
Stroke	$\pm$ 2.96 in.

These actuators are capable of providing actuation loads of 12, 390 lb in either direction. Linear potentiometers mounted inside the actuator piston rods provide proportional positioning of the actuators and record actuator positions during the test.

These actuators were selected over flight actuators because of the lack of actuation data on valves of this type. The pintle uses gases bled from the tip of the pintle to a cavity at the rear of the pintle to achieve a pressure balance which will reduce the required actuation loads. Reducing the actuation loads is important to the structural integrity of the pintle and orifice components.

Figure 26 shows the pressure balancing technique used. The degree of pressure balancing achieved is a function of the location of the pressure balancing holes, the size, and length of the holes.



7U39910

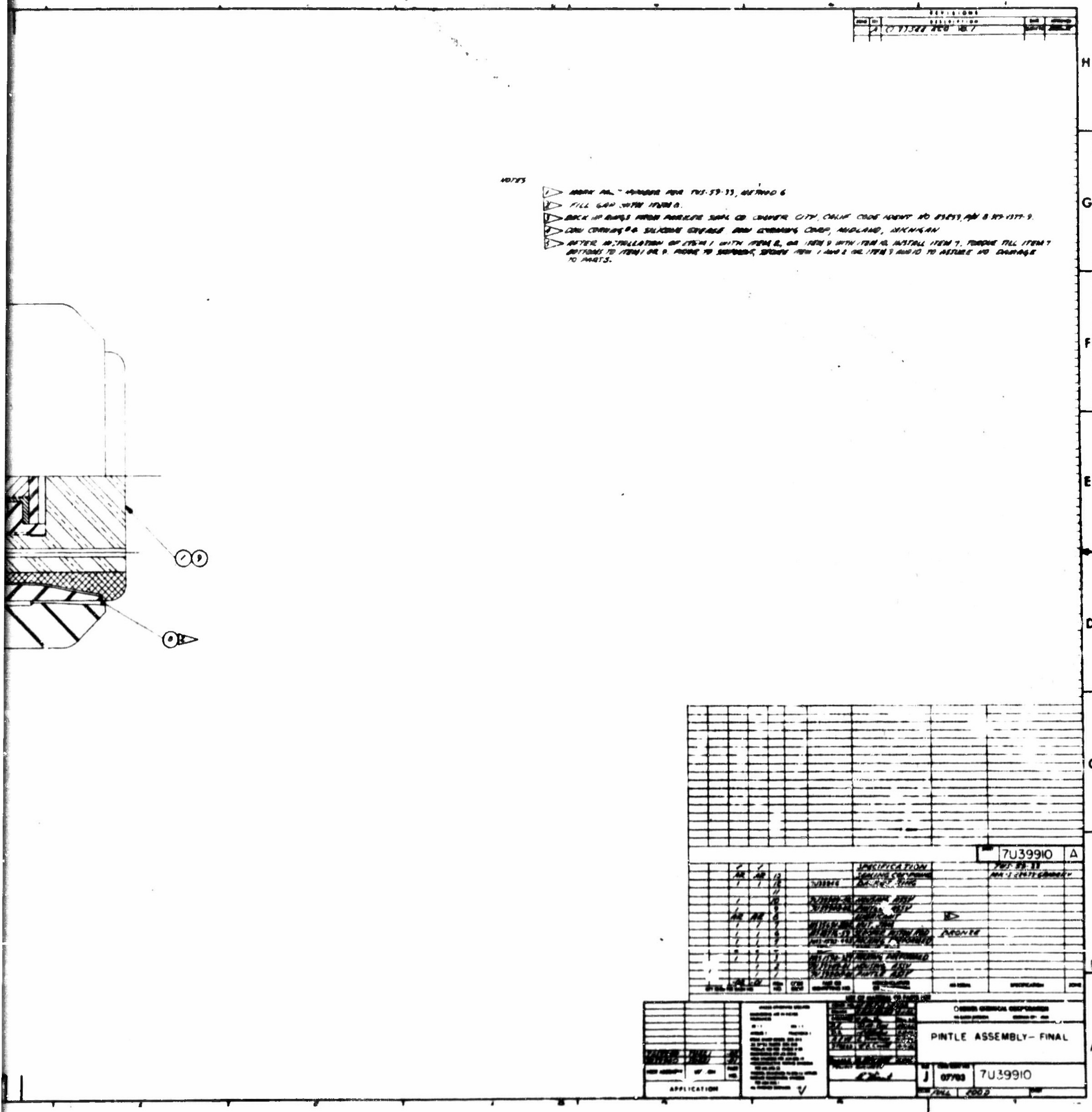


Figure 25. TU-521.01 Pintle Assembly

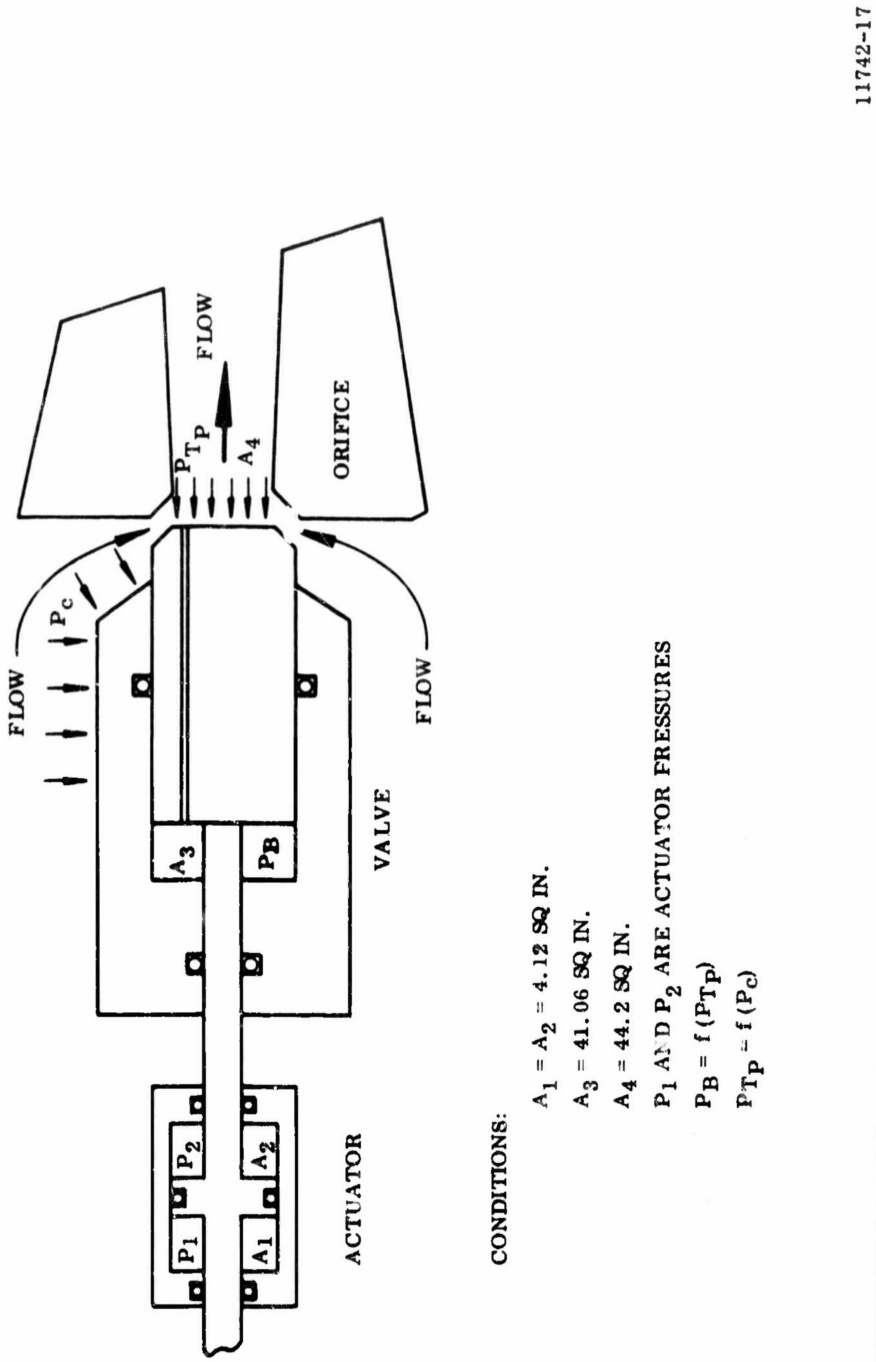


Figure 26. Valve-Actuator Configuration

Cold flow data for small pintle valves were analyzed to determine the most optimum radial location of the pressure balance holes. This location is sensitive because of the variation of the local pressure across the tip of the pintle as well as the variation in the average tip pressure with valve stroke.

Dynamic analyses were conducted to evaluate the effect of the ratio of P_B/P_{TP} on the response of the system. The ratios of P_B/P_{TP} versus P_{TP}/P_c (tip pressure to chamber pressure) were determined for phase shifts between the input signal and the actuator position equal to 15, 30, and 45 deg as well as for the stall condition. Cases analyzed included constant chamber pressures of 840 and 1,000 psi. A third case, which assumed the motor pressure fluctuated with valve stroke, was also considered.

A comparison of these three figures reveals that the extrapolated performance lies well with the investigated phase shift envelopes. Negligible phase shift is therefore anticipated during the test.

The case which assumed that chamber pressure varied with valve stroke had significantly different characteristics than those which assumed 840 and 1,000 psi chamber pressures. Examination revealed that the actuator cannot stall in the extend direction from a pressure imbalance and requires the balancing pressure to be three times the tip pressure before stalling will occur in the retract direction. These valves are widely divergent from those for the other two cases.

These curves indicated that a sufficient margin of safety exists in the selected actuator and that actuation be achieved as programed throughout the static test.

(b) Thermal Analyses--Thermal analyses of the movable pintle and pintle housing were completed. The analyses assumed that full flow occurred through the valve for 120 seconds. This heating condition is more severe than will be encountered and therefore provides conservative results.

Figure 27 shows the temperature distribution throughout the movable pintle assembly. The distribution indicates that all steel components are adequately insulated. The hottest steel component is the A-286 steel retention ring, which retains the tungsten shell in the assembly. This component has a maximum predicted temperature equal to 231° F, which will not be detrimental to component performance.

Radial thermal gradient at various time intervals is presented in Figure 28. These radial gradients clearly show that the tungsten member is the primary source of heat flow into the pintle assembly. These gradients indicate that adequate thermal mass exists to absorb the heat input, without overheating any critical components.

The valve housing was analyzed in the plane of the dynamic O-ring to assure insulation adequacy. Two valve housing configurations were evaluated: a solid carbon cloth type wrap and a composite silica and carbon cloth design. Figure 29 shows the radial thermal profiles for these configurations. Figure 29 indicates that the O-ring surface temperature will approach 250° F for the carbon cloth housing. The composite housing of silica and carbon cloth will reduce this temperature to 200° F. To evaluate which design performs better, both will be tested in the first test. A comparison of performance, fabrication, and cost parameters will then allow the best design to be selected for future application.

(c) <u>Erosion Analysis</u>--Erosion on the tip of the valve housing and tip of the pintle assembly were evaluated. Figure 30 shows the predicted erosion profiles. The worst erosion on the housing would occur with the pintle full open for 120 seconds. The tip would then be eroded back about 0.7 inch. Even with this type of erosion, the steel pintle components would be protected adequately by the housing. The erosion on the pintle tip is predicted to be less than 0.2 inch. This region is, however, difficult to analyze due to the lack of erosion data on materials in a base region such as this. Excessive recirculation could result in more severe erosion than predicted but would not result in overheating of any of the steel components because of the large distance from the tip surface to the simulated actuator (2.3 in.).

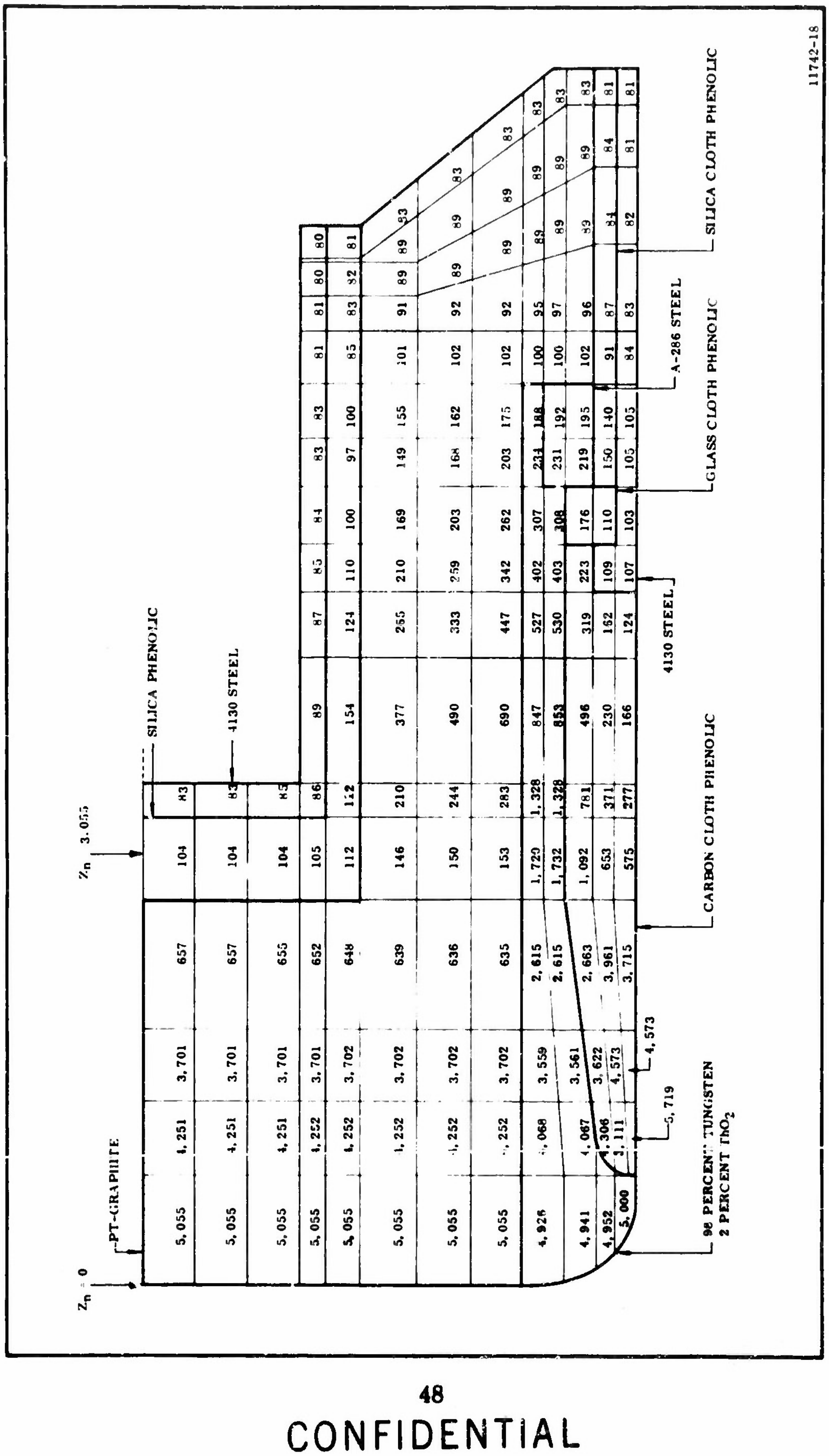


Figure 27. Prototype Pintle Temperatures (°F) at 120 Sec Full Flow

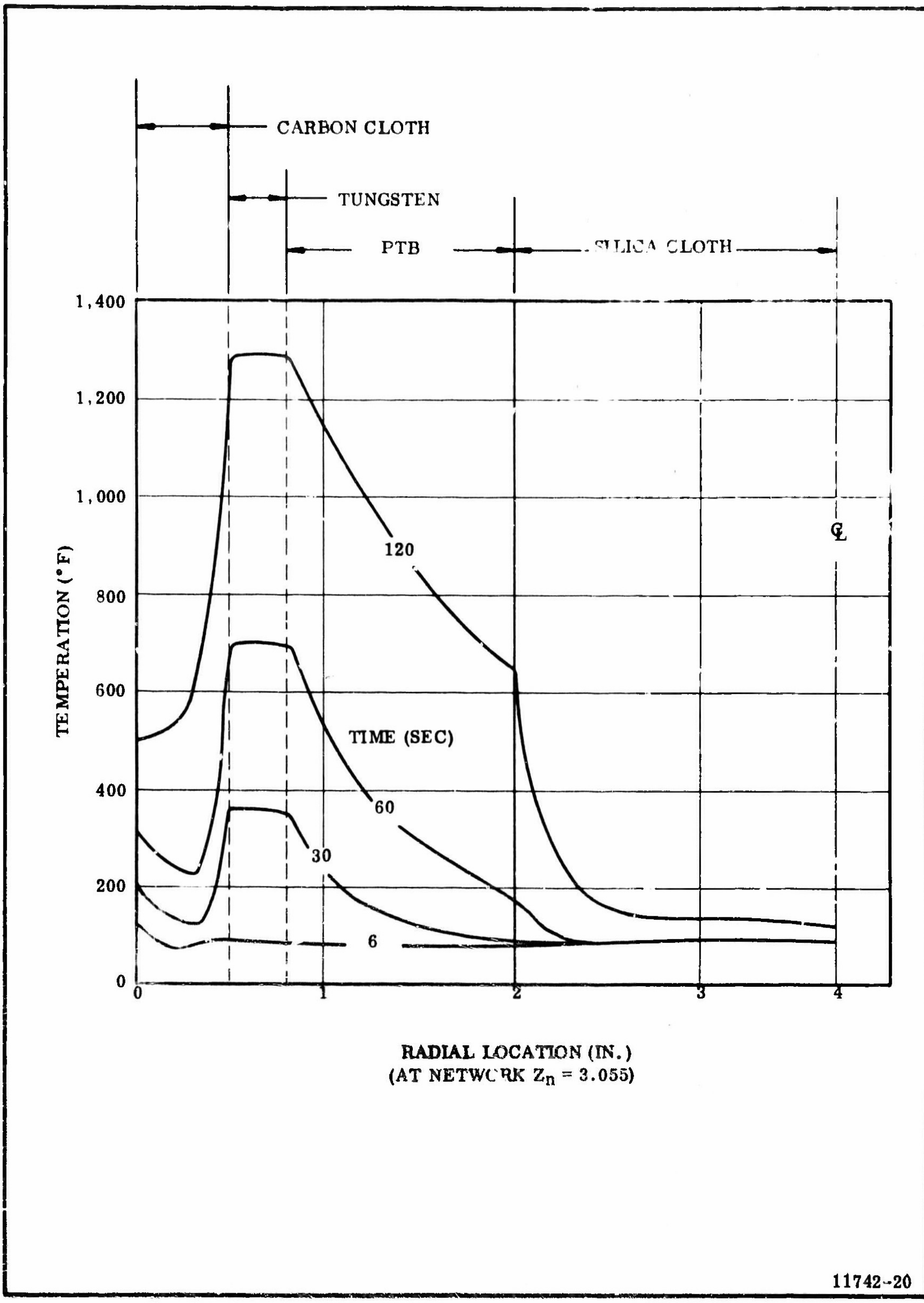


Figure 28. Radial Thermal Gradients

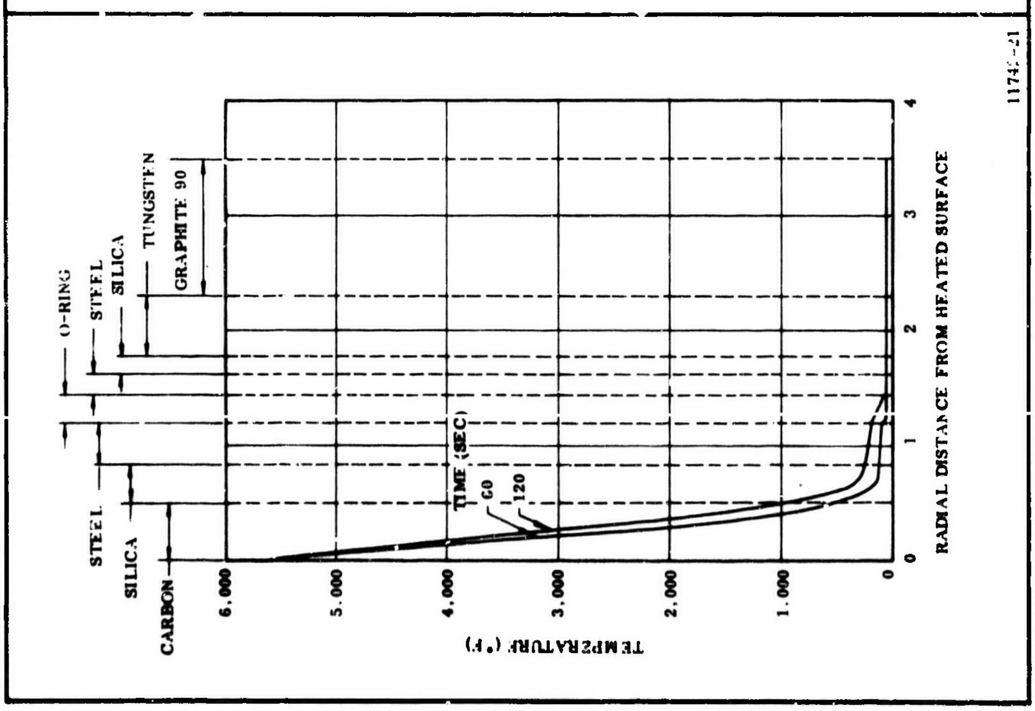


Figure 29. Predicted Temperature Gradients Through Pintle Housing

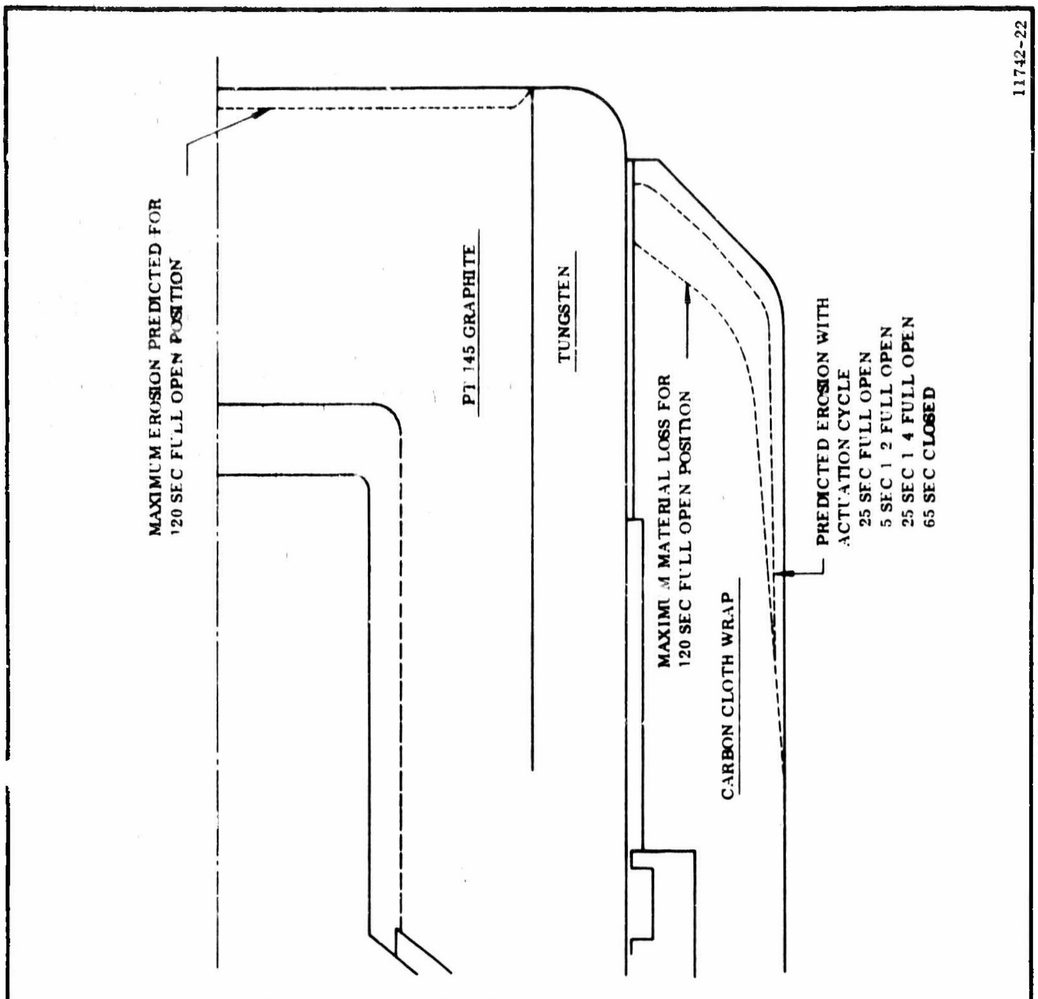


Figure 30. 120 in. Hot Gas Valve

(d) Structural Analyses--The movable pintle assembly is the most critical component in the valve. This component must modulate the flow of gases through the valve orifice and resist erosion. Dynamic actuation loads and pressure induced forces must be resisted by the various pintle components.

The major forces are the actuation loads transmitted into the steel retention ring at the end of the tungsten shell by a threaded connection. The retention ring transmits these loads through a glass cloth bearing ring to the outer steel link which is threaded to the actuator housing.

These critical components were analyzed structurally to assure their adequacy. A brief discussion of each component follows.

1) Tungsten Shell--No structural problems exist when thermal gradients are neglected. The thermal gradients predicted along the axial length of the tungsten shell (Figure 31) induce thermal stresses in the tungsten which cannot be handled by conventional methods due to the necessity of accounting for changing mechanical properties (modulus, thermal expansion, etc.). Combined on top of these problems is the wide range of thermal gradients which are attainable. These gradients are a function of the assumed heat input (duty cycle, no duty cycle, etc.), the assumed radial heat transfer from the tungsten shell to the valve body (zero, full contact, radiation only, etc.), the thermal insulator on the O.D. of the tungsten shell, and the time interval selected.

Obviously all possibilities cannot be considered and actual analysis techniques are not adaptable to materials with varying moduli of elasticity. Analyses conducted must, therefore, be considered as indicators of performance only.

A discontinuity analysis of the tungsten shell was conducted. For this analysis, the shell was divided into a series of rings, cones, or cylinders (members). The temperature at the center of each section was used to determine the modulus of elasticity and radial thermal expansion of the section. The thermal gradients presented in Figure 31 were used. This analysis procedure was especially

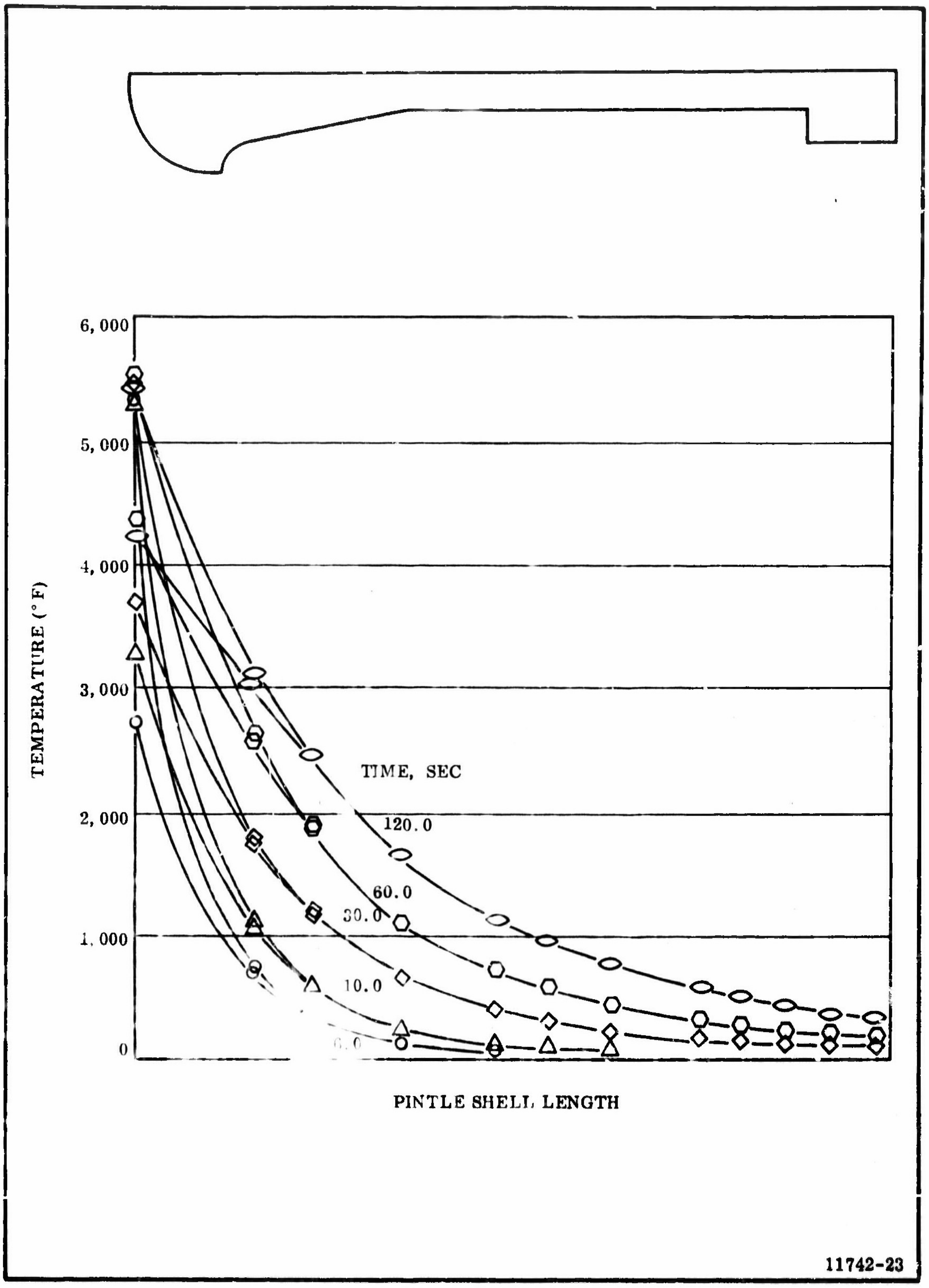


Figure 31. Tungsten Shell Temperatures

severe because it resulted in the physical displacement of the adjacent members from each other. The solution technique used forces these members to deflect until a continuous structure is achieved (satisfies the deflection and rotation equations for the structure). This forced deflection and rotation requires hoop and meridional stresses at the ends of each member. Figure 32 presents calculated hoop and meridional stresses resulting from the thermal gradients and the actuation and pressure loads at 6.0, 60.0 and 120.0 seconds. Also superimposed is the yield strength along the shell length (Figure 33). Evaluation of the three figures showed that the hoop stresses may exceed the yield strength at 6 sec while the meridional stresses on the inside diameter of the shell may exceed the yield strength at 60 and 120 sec in local zones. The overall stress picture in the shell was excellent with the exception of the above noted conditions.

The stresses presented are probably higher than will actually exist due to the analyses techniques used. Evaluating the areas where the yield stresses exist indicated that the temperature in all cases was above the ductile to brittle transition temperature (450° F) for this material. Stress relief by local yielding is, therefore, expected if the yield strength of the tungsten is exceeded.

The analyses indicated that the pintle shell is structurally sound and that axial thermal gradients will not induce component failure.

2) Retention Ring--The retention ring was subjected to shear stresses in the threads which connect it to the pintle shell. Calculations indicate that the temperature of the connecting link must approach 1,570° F before a shear failure will occur. The predicted temperature is only 230° F. At 230° F, the minimum margin of safety would be 13.2, which will assure satisfactory operation.

3) Bearing Ring--The glass cloth bearing ring was subjected to flexural shear and bearing stresses. Flexural stresses will exist and will cause the ring to rotate slightly, resulting in the transmission of the loads from the

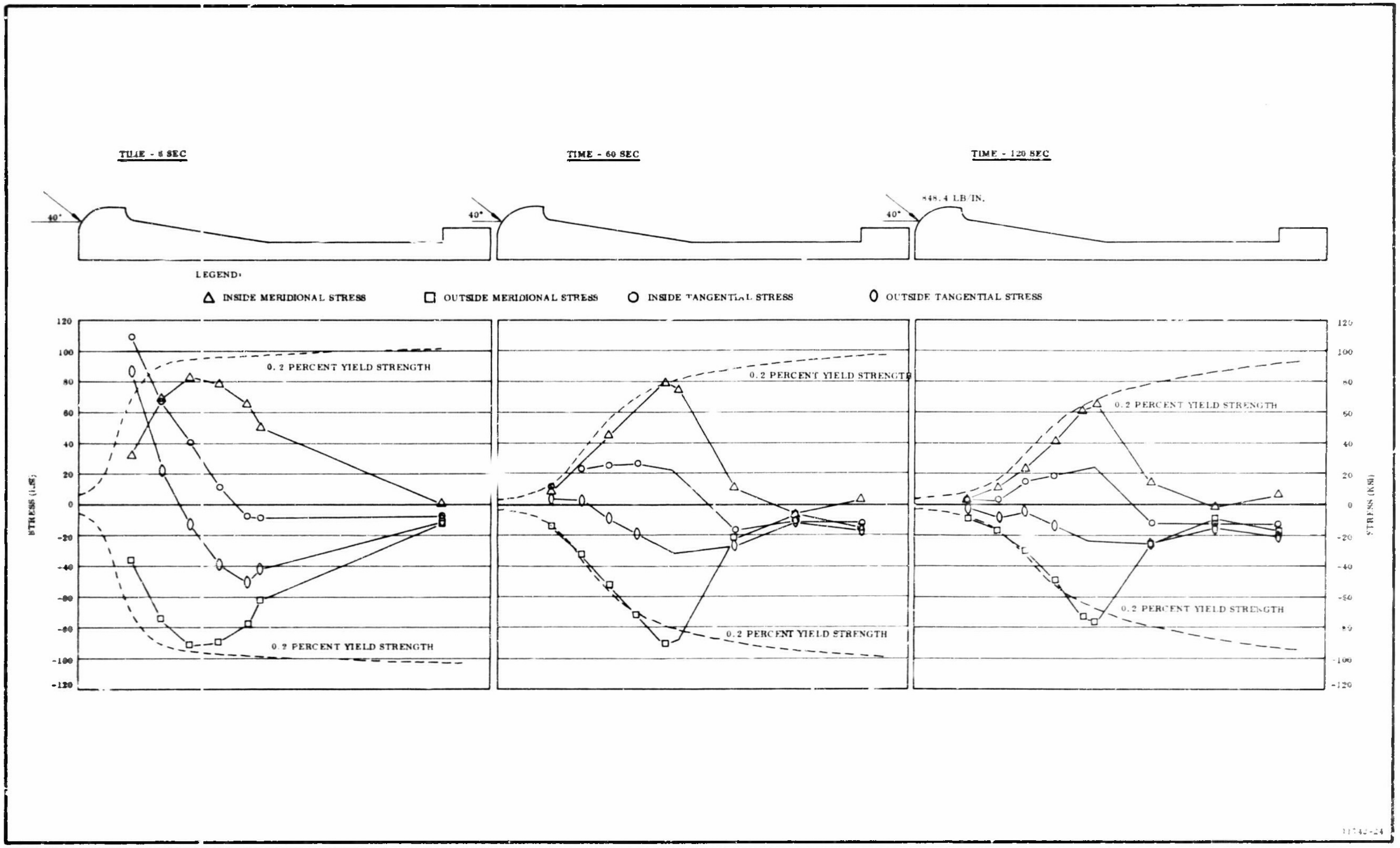


Figure 32. Calculated Hoop and Meridional Stresses Resulting from Thermal Gradients and Actuation and Pressure Loads at 6, 60, and 120 Seconds

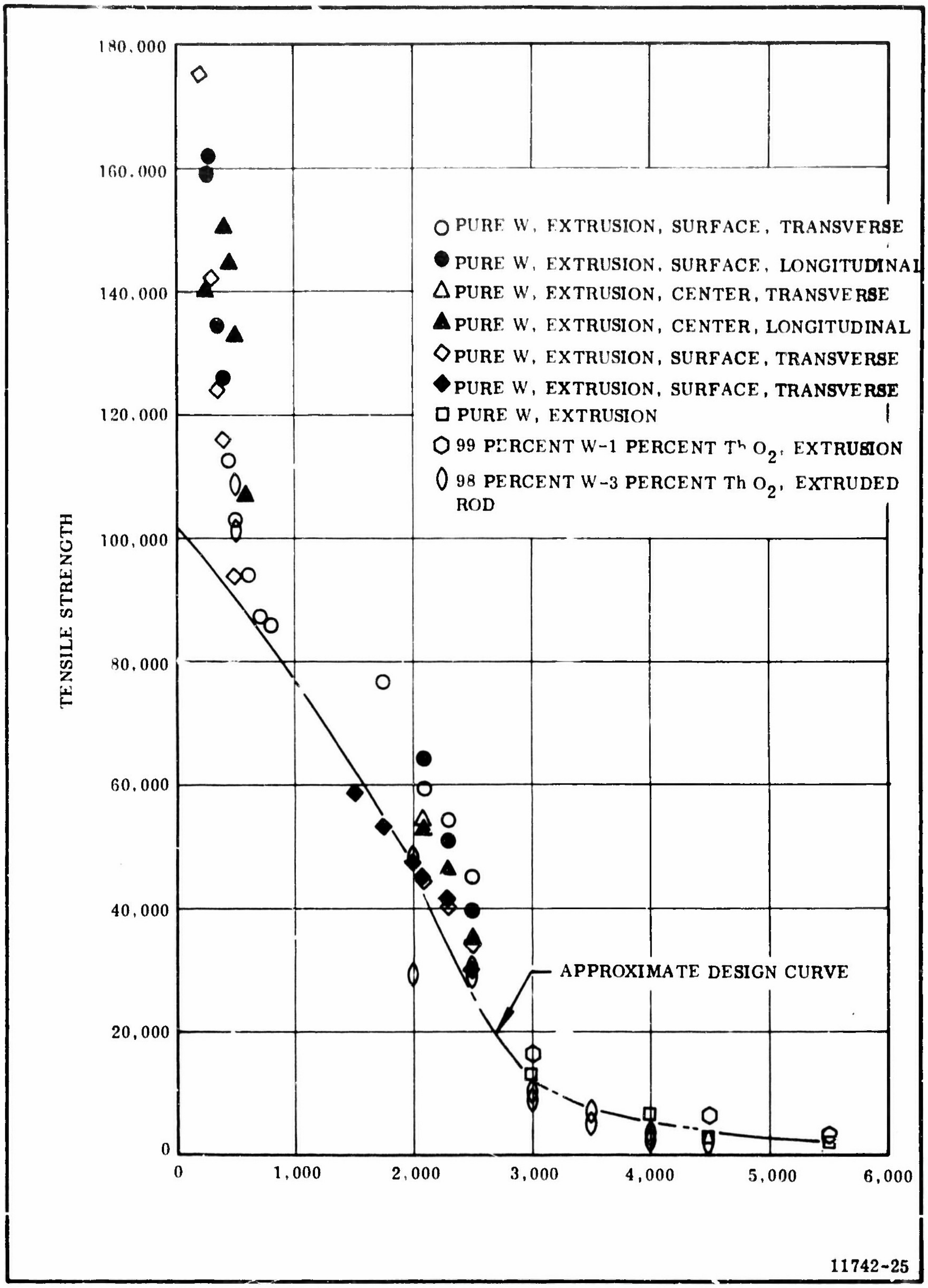


Figure 33. Yield Strength Along the Shell Length

retention ring to the connecting link in shear and bearing loads. The minimum margins of safety for these two load transmissions are 0.432 in shear and 0.51 in bearing.

This part will perform satisfactorily.

4) Connecting Link--The connecting link will be fabricated from 4130 steel. This member was subjected to bending at the forward end, tensile and hoop stresses along its length, and shear stresses in the thread which connects it to its actuator.

Based on conservative assumptions, the minimum margin of safety is 0.17 for bending at the forward end of the part. If more realistic assumptions were used, a margin equal to 0.45 exists. Margins for the shear stress, tensile stress, and hoop stress are 16.6, 16.2, and 1.6, respectively.

5) Other Components--Other more noncritical components were analyzed during this quarter, and no structural deficiencies were observed.

(2) Second Component Test (TU-521.02)--The design of the test hardware was initiated but only the analysis of the flightweight actuation system (valves No. 3 and 4) has progressed sufficiently to warrant inclusion in this report. The actuator parameters are as defined in the section on the baseline system.

(a) Actuation System--Dynamic analyses were conducted to assure that adequate performance will be achieved. These analyses used maximum predicted loads resulting from a pressure unbalance of 8,000 lb opposing actuator extension (valve shutting) and 2,225 lb opposing actuator retraction.

The dynamic analyses also determined the ratios of P_B/P_{TP} which would force the actuator to be 15, 30, and 45 deg out of phase with the input signal. A comparison showed that only minor envelope increases will occur with the pressure decrease in the retract direction. Larger envelope changes will occur in the extend direction. Data from the first test will be used with these curves to evaluate the actuator adequacy in light of measured ratios of P_B/P_{TP} versus P_{TP}/P_c.

Additional analyses were conducted to determine the ratios of P_B/P_{TP} which will exist after burst disc rupture. Figure 34 presents the results and indicates that only a retract envelope exists. This is consistent with the analyses for the first two valves, which will use facility actuators. This curve also indicates that a ratio of P_B/P_{TP} equal to 1.5 may exist without adversely affecting actuator performance. Such a ratio would be virtually impossible to achieve in actual practice. Satisfactory performance is therefore expected after burst disc rupture.

c. <u>Valve Orifice Design</u>--The following design requirements were used to design the full scale valve orifice.

1. Maximum expected operating pressure, 1,000 psia.
2. Chamber gas temperature, 5,800° F.
3. Web burn time, 120 sec.
4. HGTVC loads
   a. Seating load (maximum), 14,700 lb.
   b. Unseating load (maximum), 12,350 lb.

The injection port assembly (Figure 35) consists of an outer structural and insulative conical sleeve of carbon cloth lined with erosion resistant graphites and a 2 percent thoriated tungsten throat insert.

The inlet section consists of Graphite 90 which has excellent erosion resistance and heat sink properties. It also supports the tungsten insert. Downstream as backup liner for the lower throat section and divergent cone section contour is a PTB fibrous graphite phenolic molding insert.

Orifice port dimensions and characteristics are listed below.

1. Throat, 6.50 in. diameter.
2. Length: inlet to exit, 9.25 in.
   throat to exit, 8.68 in.
3. Expansion ratio, 1.3/1.0 exit/throat.
4. Exit diameter, 7.4 in.

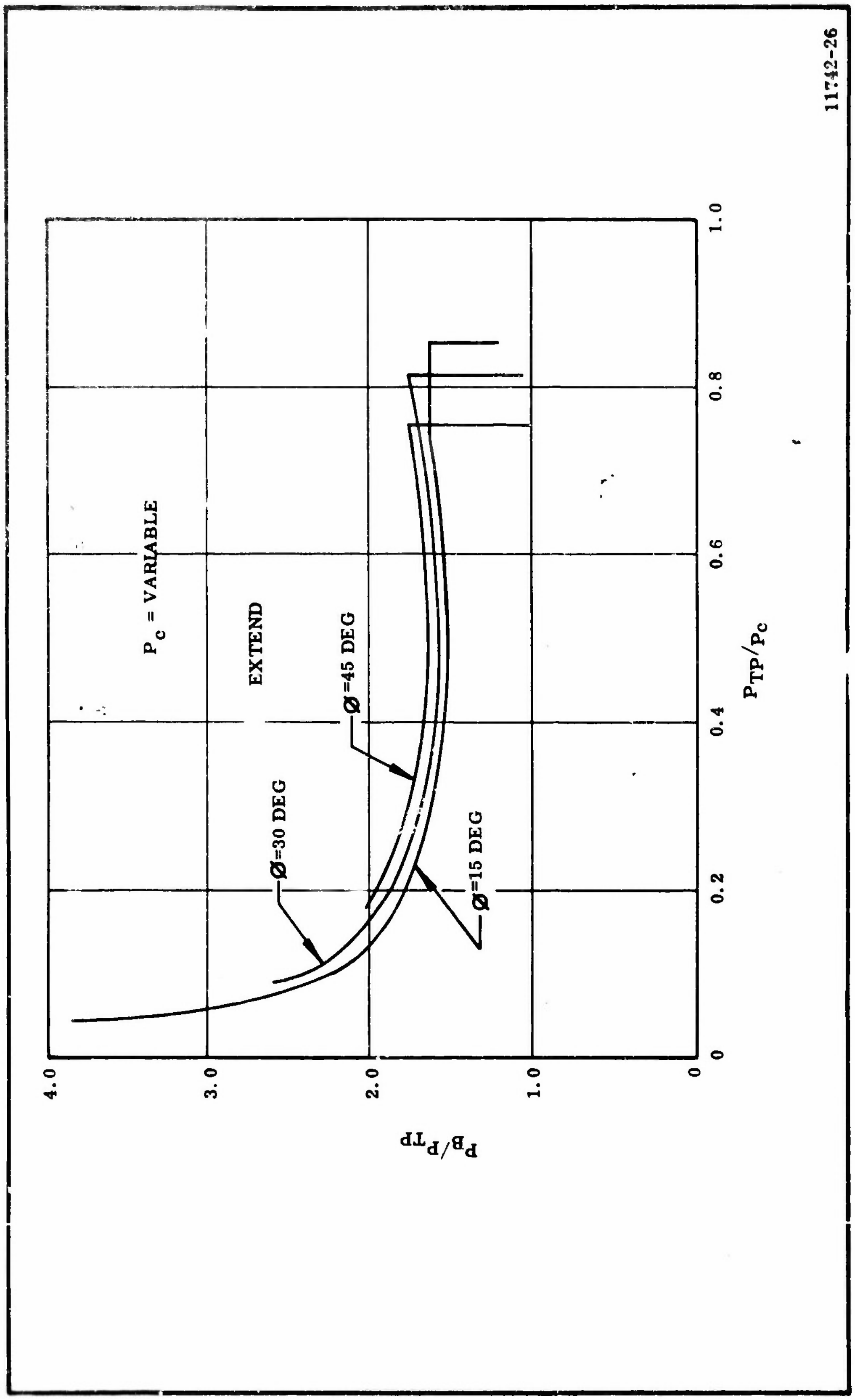


Figure 34. P_B/P_{TP} vs P_{TP}/P_c at Variable Chamber Pressure

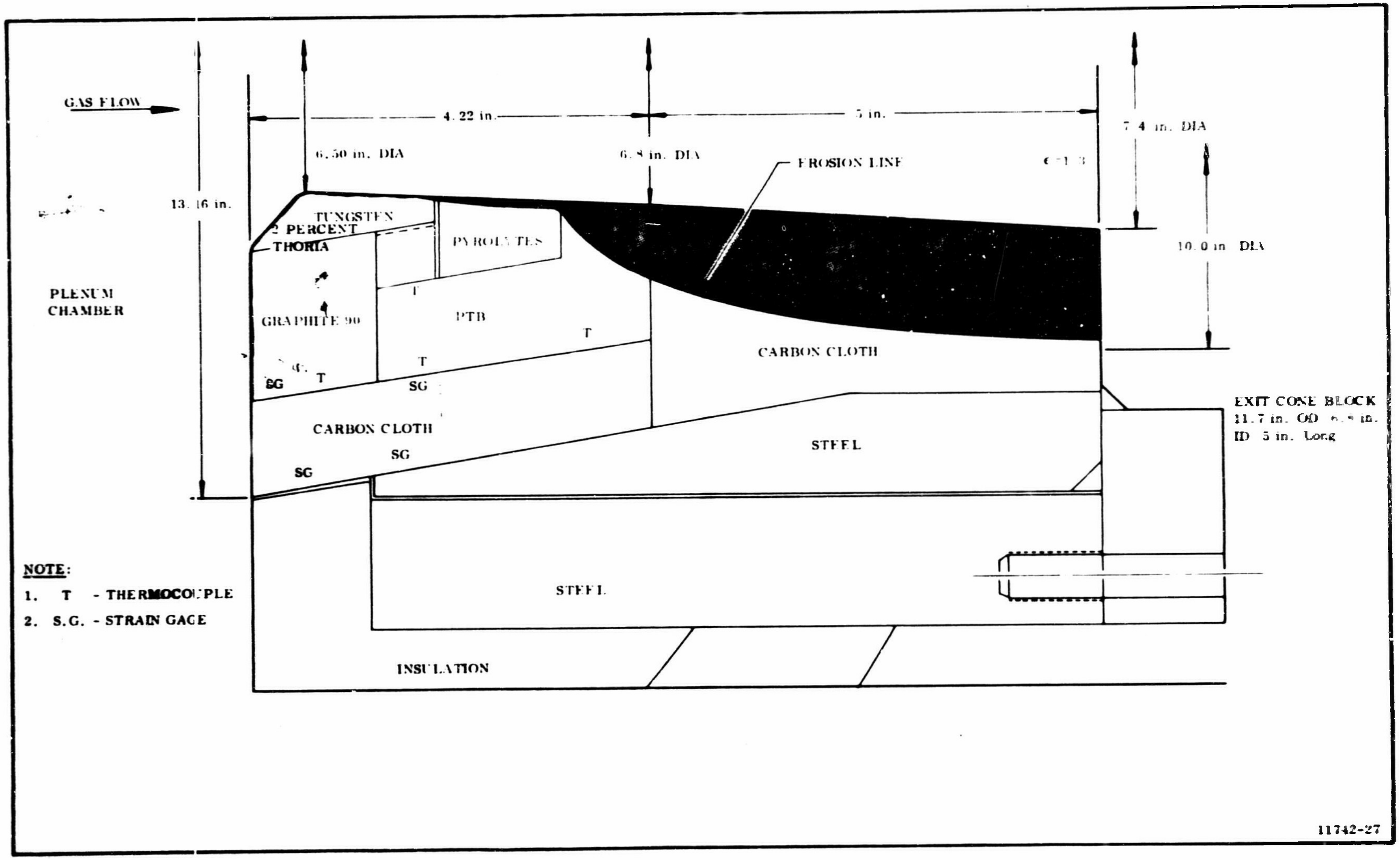


Figure 35. Injection Port Assembly

5. Exit cone half angle, 3 deg.
6. Instrumentation to be installed for first test:
   five thermocouples.
   four strain gages.

The following materials and properties were used to analyze and design the orifice.

1. Sintered copper impregnated tungsten.
2. Extruded thoriated tungsten.
3. Pyrolytic graphite washer.
4. PTB graphite molding reinforced with graphite cloth.
5. Carbon cloth phenolic rosette.
6. Extruded Graphite 90.

The thermal gradient for the orifice at 120 sec is shown in Figure 36. These results indicated that the orifice design is adequate for thermal protection and survival. The predicted erosion is shown in Figure 37 with the largest amount in the exit cone.

The orifice port was designed by imposing the shear load on the conical seats of the extruded thoriated tungsten throat, copper impregnated sintered tungsten nut, and pyrolytic graphite washer bearing plate.

The tungsten port loads for the seating and unseating condition are listed below with the factors of safety at elevated temperature.

	Acting Loads Total (lb)	Reaction Load Capability (lb) Insert	Nut	Brg Plate	Total
Impact	27, 150	25, 400	16, 320	21, 600	63, 320
Retraction	5, 480	--	16, 320	--	16, 320

$$\text{Impact Load F.S.} = \frac{63,320}{27,150} = \underline{\underline{+2.33}}$$

$$\text{Retraction Load F.S.} = \frac{16,320}{5,480} = \underline{\underline{+2.98}}$$

11742-28

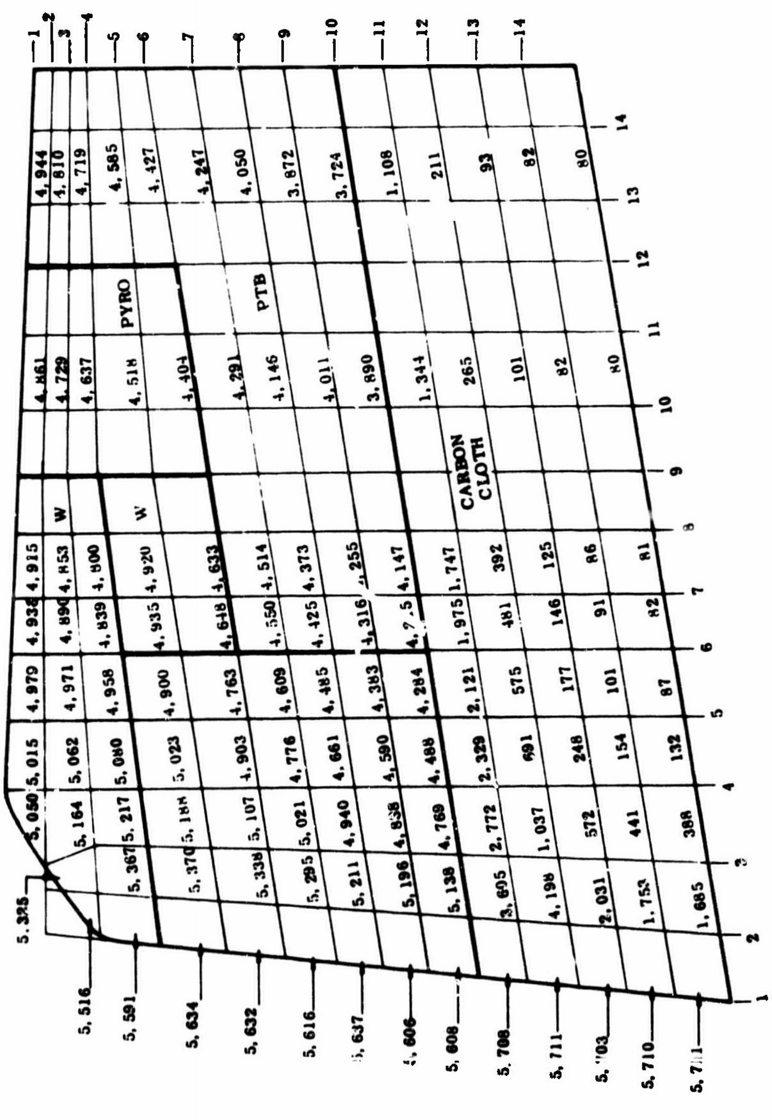


Figure 36. Thermal Gradient for Orifice at 120 Sec

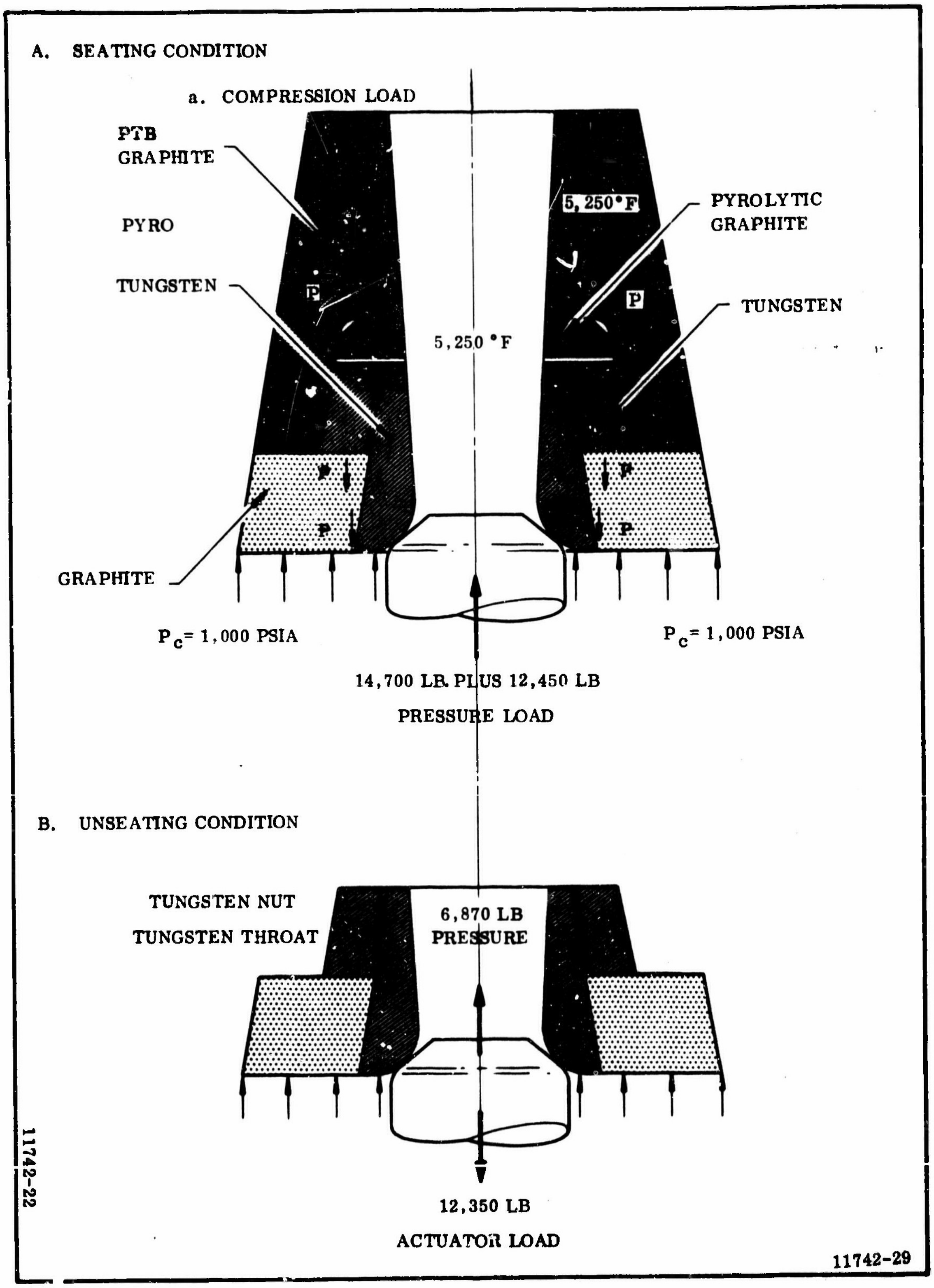


Figure 37. Tungsten Port Loads

B. PHASE I DEVELOPMENT SUPPORT

1. PROPELLANT TAILORING

The propellant selected for the 65 in. diameter motor tests is an uncured PBAA formulation designated as TP-H1113. The composition of this propellant is shown below.

Propellant Ingredients	Lot No.	Percent by Weight
HB Polymer	9404-0085	10.0
DOA	9195-0004	3.0
Aluminum	9008-0055	16.4
Iron Oxide	9451-0002	0.6
AP	9015-0179	70.0

This propellant was thoroughly characterized during previous Thiokol programs. The target burning rate is 0.53 in./sec at 700 psia, and the flame temperature is 5,750°F.

During this first quarter, effort was expended to tailor the burning rate of TP-H1113 to meet the contract requirement of 0.526 in./sec. To meet this requirement the AP bimodal was varied over a wide range with a series of 1,000 gm mixes and three series of 2 1/4 gal. mixes. The ground fraction of the AP was varied from 40 to 70 percent.

The results of strand rate tests at 700, 1,000 and 1,500 psi are plotted in Figure 38 . Extrapolation of these data in conjunction with an adjustment factor for the burning rate of strands in comparison with motor data constituted the basis for selecting the bimodal blend range for the first series of 2 1/4 gal. mixes.

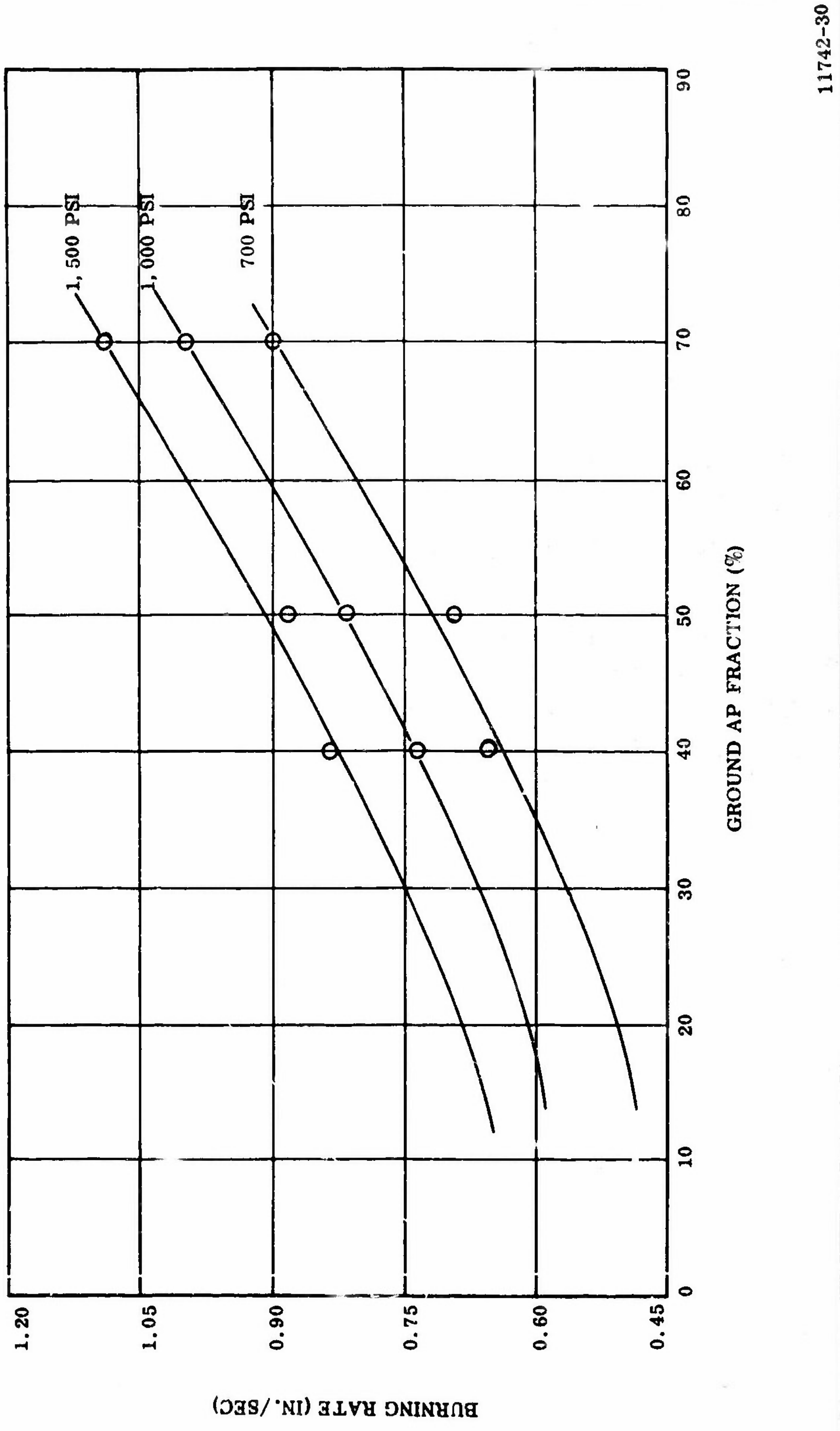


Figure 38. TP-H1113 Strand Burning Rate vs Ground AP Fraction

Three 2 1/4 gal. standardization mixes were made with the same lots of raw material that will be used to cast the 65 in. diameter motors. The ground AP fraction selected was 15, 20, and 25 percent. In addition to the uncured strands, six TU-379 motors (4.2 in. diameter, 4 in. long end burner) were cast from each batch. The 85/15 bimodal mix did not deaerate properly and was discarded. Figure 38 shows the data obtained on the propellants with 80/20 and 75/25 bimodal distributions. These data show an unexpected shift in burning rate, which can hardly be attributed to a change in the lot of the ingredients from the Hobart to 2 1/4 gal. mix.

The TU-379 data, calculated by two methods, are plotted in Figure 40. In one method, 3 percent of the integral of the pressure vs time trace was subtracted from the start of the trace. This 3 percent corresponds to the slab of cured low rate propellant used to smooth out the ignition transient. The second method represented a best estimate of the start of burning on the basis of the shape of the burning trace. These data corresponded fairly close to the strand rates, but the uncertainty necessitated the preparation of more mixes.

Two series of 2 1/4 gal. mixes were subsequently prepared, the first with epoxy curing agent (ECA) and the second without the curing agent. In the first, TU-172 motors (2 in. diameter CP) were cast, and in the second, TU-379 end burner motors were cast. Uncured strands were obtained on both mixes.

The TP-H1113 containing ECA was formulated at the 25, 30, and 35 percent ground AP fraction. The strand burning rate data in conjunction with that obtained on the previous 2 1/4 gal. series is presented in Figure 39 . Extrapolation of these data show a 45 percent ground fraction should yield the 0.53 in./sec at 700 psia target burning rate. Consequently, 2 1/4 gal. uncured TP-H1113 propellant mixes are being prepared at the 30, 38, and 45 percent ground AP fraction levels.

The processing characteristics of the TP-H1113 prepared in the 2 1/4 gal. mix indicated that there should be no problem in casting the 65 in. diameter motors. End of mix viscosity ranged from 10 to 16 kp at 145°F.

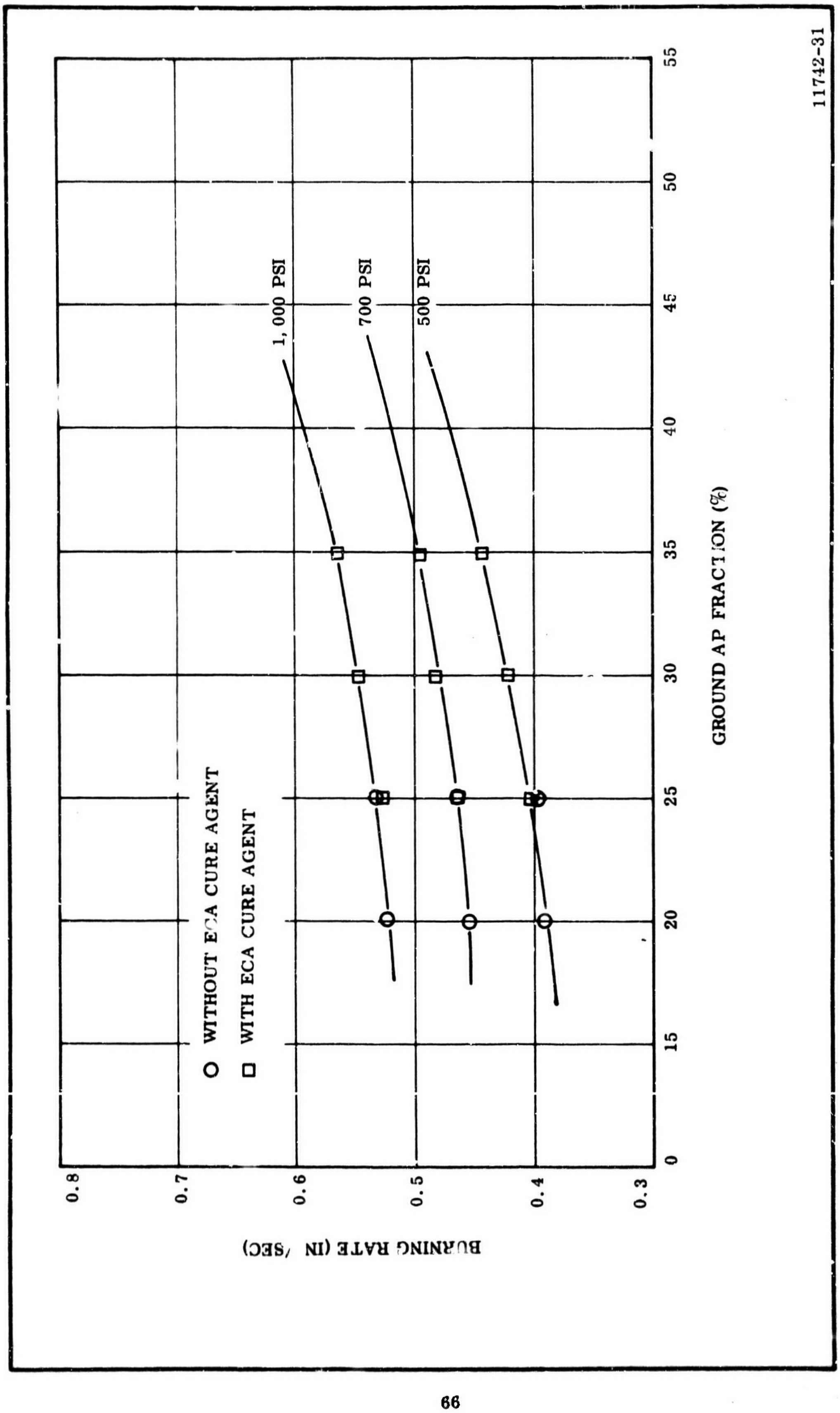
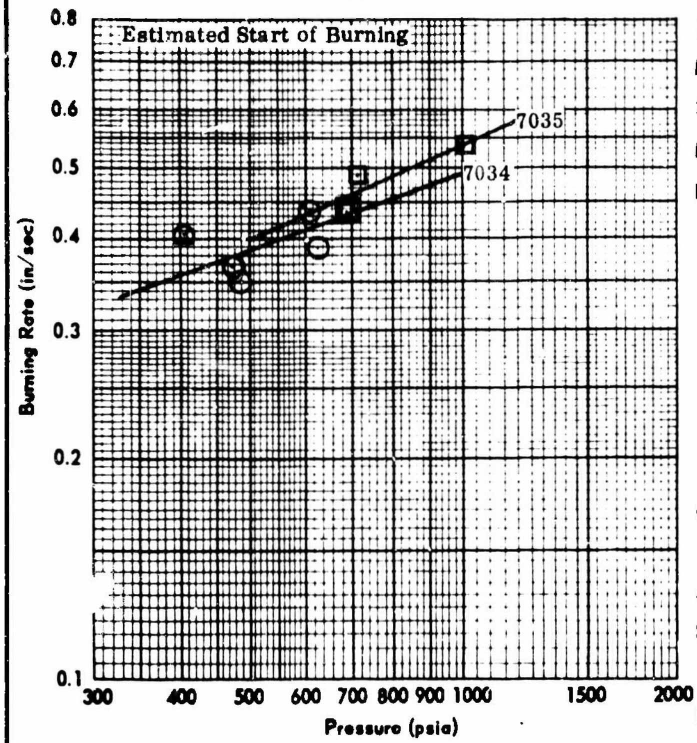


Figure 39. TP-H1113 Uncured Strand Burning Rate vs Ground AP Fraction



Propellant Type TP-H1112

Mix Number

PWR No.

Motor Type TU-379

Number of Motors

COMPOSITION

⊙	7034	80/20 Bimodal
⊡	7035	75/25 Bimodal
◠	7034	Without Igniter Slab

Oxidizer grind ratio:

MEASURED BALLISTICS

Average C*, ft/sec

Specific impulse

@ 1000

Rate @ 500 @ 1000

R_b

K_n

π_k

MEASURED PHYSICAL PROPERTIES

Modulus

Maximum stress

Stress @ Maximum strain

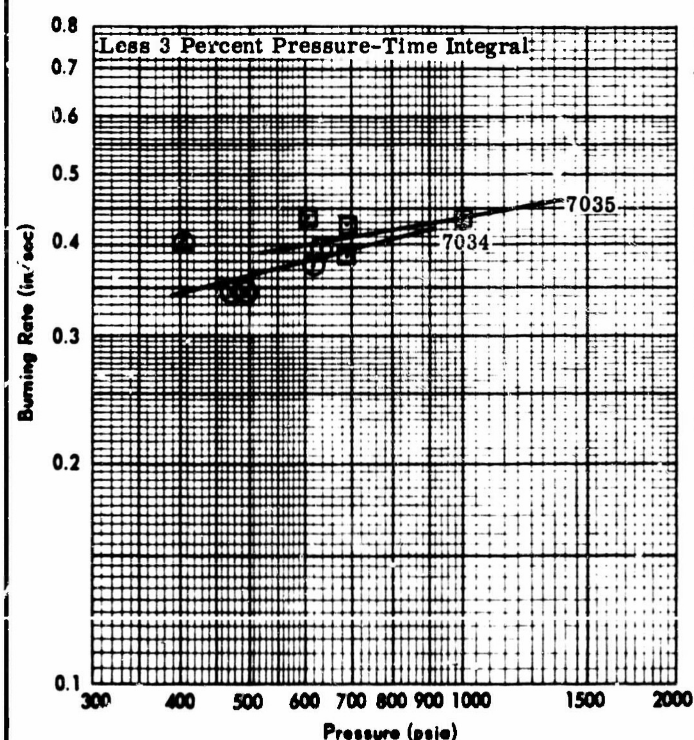
Strain @ Maximum stress, %

Strain @ Cracking, %

Density, lb/in^3

Shore "A" hardness

Tear Resistance



Burning Rate:

A. Estimated Start of Burning
7034 - 0.43 in./sec
7035 - 0.455 in./sec

B. Less 3 Percent Pressure Time Integral
7034 - 0.392 in./sec
7035 - 0.414 in./sec

11742-32

Figure 40. Performance Data for TU-379 Motor (uncured end burner)

2. IGNITION SYSTEM BENCH TESTING

The TU-521 igniter will be assembled and static tested in the TU-P122 igniter static testing stand. The stand will be modified by drilling two or three holes in it to match the 14 in. bolt circle on the TU-521 igniter adapter.

The test instrumentation will be pressure transducers to measure igniter chamber pressure and two Fastax cameras, one mounted directly aft of the igniter to record the flame pattern radially and one to the side to record the angle of the plume with respect to the case centerline.

The bench test procedure is being prepared.

3. BURST DIAPHRAGM BENCH TESTING

Two prototype burst diaphragms for the TU-521 motors will be bench tested. The test fixture is being designed and the bench test procedure is being prepared.

C. OPERATIONS

1. MANUFACTURING

a. Manufacturing Plan--The preliminary Manufacturing Plan is completed and is currently being revised to incorporate the latest design and processing changes. The plan will be completed and formally transmitted to the customer prior to actual motor manufacturing.

Thiokol's original plan was to use uncured inert propellant as a filler material in the short duration motors. Further analysis has shown it to be advantageous for processing and economic reasons to remove and discard the existing uncured inert propellant and replace it with MACRAP. MACRAP is an inexpensive filler material consisting of sand (77.5 percent), resin (12.5 percent), and [illegible]mer (10.0 percent). It has proven to be highly successful on other programs. The material can be refurbished for the second short duration motor by removing the char material and topping it off with new material. All of the MACRAP can be removed for the third motor by heating the case to 400°F. At this temperature, the bond strength of the material deteriorates and facilitates easy removal.

The plenum chamber insulation will be hand packed and contoured using molds to form the opening at each port. The initial plan was to mold the complete plenum chamber cavity, but the effect of a hand formed versus molded cavity on performance is insignificant and does not justify the mold cost. The primary function of the insulation is to protect the metal parts.

Other motor processing is essentially the same as originally planned and described in the Program Plan.

b. Refurbishment of Hardware--Aft closure modifications have been in progress since early May. Difficulties were encountered in meeting the drawing weld requirements. The first welds were made using conventional arc welding techniques.

The massive size of the welds required approximately 35 passes to complete one fillet. Grinding was required at the start and stop of each rod, resulting in a time consuming operation. In addition, radiographic inspection of the first fillets in each ring/flange weldment revealed slag and/or porosity which exceeded specification limits. The repair cycle resulted in schedule delays. Hand grinding to remove the defect and the radiographic check to assure complete removal required additional time.

In an attempt to improve the schedule, it was decided to subcontract the repair and welding of one ring/flange subassembly. The second weldment was completed inhouse. Concurrent with the processing of the ring/flange weldment, the weld shop, in conjunction with Process Engineering and Engineering Metallurgy, was developing the MIG (metallic inert gas) welding process and certifying welders to the new process. The MIG process is a continuous consumable wire electrode shielded by carbon dioxide gas. This process offers a superior quality weld in much less time. The MIG process has been incorporated for welding the ring/flange subassemblies to the aft closure. Radiographic inspection results of parts welded using the MIG process have been encouraging.

The aft closure fabrication problems and late delivery of other hardware items have resulted in a hydrotest schedule delay. A blankoff plate will be used as an alternate for the burst disc on the auxiliary port because of the long procurement lead time to obtain the burst disc.

The TU-521 motor case is in storage and has been reserved for this program.

c. Assembly of Test Motors--Considerable effort was expended during this quarter on establishing motor component and material requirements and initiating procurement. Surplus Stage I MINUTEMAN propellant raw materials have been transferred to this program and are in storage.

Surplus graphite billets were used to machine the graphite parts for the aft closure blast tubes. These parts have been delivered to a subcontractor for wrapping with graphite cloth materials.

Modified igniter designs were completed late in this quarter. Igniter component and material requirements were established and procurement action has been initiated. Igniter case modifications were also started. Modification of the igniter casting tooling was initiated. Igniter manufacture is scheduled to start in late June 1966.

Actual test motor assembly is scheduled to start during July 1966.

2. TOOLING DESIGN AND FABRICATION

Tooling requirements for motor manufacture were established. Existing tooling was used wherever possible. A minimum number of new tools have been designed and fabricated. These tools are primarily positioning fixtures and templates for insulating the motor case, closure, and plenum chambers and modifications to existing igniter casting tooling.

3. QUALITY ASSURANCE

The Quality Assurance Plan for this contract was written, submitted to the customer for comments, and revised in accordance with the comments received. The revised Quality Assurance Plan will be transmitted to the customer in June 1966.

The Quality Assurance Plan describes the quality assurance system at the Wasatch Division. The elements of the quality assurance system that were emphasized as applicable to this program were drawing review, procurement control, subcontractor control, inspection planning, receiving inspection, manufacturing planning, process inspection, special processes, control of nonconformances, final and test inspection, post fire inspection, metrology, product acceptance, chemical analysis, and propellant characterization.

An Appendix A has been attached to the plan to describe the propellant, liner, and sealant raw materials to be used and the method to be used to accept the materials.

Appendix B has also been added, which specifies the specific tests to be conducted to accept the surplus raw materials being obtained from the 260 Inch Motor Program.

a. Design--The Wasatch Division's Quality Assurance organization participates in drawing and specification review to assure that quality requirements are referenced as required. This effort has been conducted during the first quarter on all drawings and specifications released to date. Although the present system has been to review these drawings and specifications immediately upon release and changes made prior to use, the Quality Assurance Plan will make provision for review and signature prior to release. This will accelerate and simplify the process of correcting drawings and will increase the effectiveness of the Quality Assurance organization.

In reviewing drawings and specifications, special attention is given to the applicability of referenced specifications and the applicability of nondestructive testing techniques, assuring that defect criteria are contained on the drawings or within the referenced specifications. This will assure that the part as dimensioned can be dimensionally inspected, and that all other Quality Assurance requirements are adhered to.

b. Propellant Tailoring--All raw materials used for the propellant standardization program are acceptable materials. Table III contains the acceptance data derived from testing these materials.

c. Procurement Control--Ogden Iron Works was given a contract to fabricate the plenum chambers. The welding of the chambers requires welding thicknesses in excess of two inches. To prepare for acceptable welding techniques, an individual welder performing the work had to be certified by Thiokol Quality Engineering. This was accomplished for one welder.

Welder certification requires the welding of typical specimens to the parts being fabricated as a demonstration of the welder's ability to perform a good weld. The specimens are then tested by visual inspection, macro examined, X-rayed, and subjected to magnetic particle inspection and bend testing.

TABLE III

MATERIAL ACCEPTANCE DATA

Aluminum Powder Lot 9008-0055: 3 year retest

Test Data	August 1964
Free aluminum, percent	99.8
Volatile matter, percent	0.02
Average particle size, microns	14.8
Weight mean diameter, microns	41.3
Total specific surface, cm^2/gm	783
Iron, percent	0.38

Ammonium Perchlorate Lot 9015-0179: 1.5 year retest

Test Data	February 1965
Moisture, percent	
Total	0.04
External	0.01
Internal	0.03
Acid insolubles, percent	0.003
pH	6.3
Perchlorate as $NH_4\ ClO_4$, percent	99.0
Phosphate as TCP, percent	0.16
Particle size, percent retained	
No. 40 sieve	0
No. 50	6
No. 70	29
No. 100	70
No. 140	94
No. 200	99

TABLE III (Cont)

MATERIAL ACCEPTANCE DATA

HB Polymer Lot 9404-0085: Yearly retest

Test Data	August 1964	July 1965
Viscosity, poise, 25°C	330	330
Specific gravity, 25°C/25°C	0.936	N/A
Acid number, eq/100g	0.063	0.063
Chloride as chloride ion	0.36	N/A
Moisture, percent	0.05	0.06
PBNA, percent	1.0	N/A
Ammonyx G, percent	4.6	N/A
Acrylonitrile, percent	11.8	N/A
Volatiles, percent	2.0	N/A
Sulfur, percent	1.2	
Heat of combustion	10.0	N/A
Iron, percent	0.005	N/A

Iron Oxide 9451-0002: 3 year retest

Test Data	February 1964	May 1965
Moisture at 105°C, percent	0.06	N/A
Calcination loss, percent	0.20	N/A
Iron, percent as Fe_2O_3	99.8	99.5
Specific surface, M^2/g	4.0	N/A

Dioctyl Adipate Lot 9195-0004: 0.5 year retest

Test Data	July 1965	May 1966
Specific gravity, 25°C/25°C	0.921	N/A
Moisture, percent	0.04	0.05
Assay, percent	100	99.5
Acid number, mg KOH/g	0.07	N/A
Refractive index	1.4456	N/A

d. Material Review--The aft closure chosen required modification by welding on a blast tube extension to two ports upon which the plenum chambers are to be mounted. The closure modification is being done at Thiokol. Welding of thick sections is required for this work. The initial welding resulted in an MRB action for each tube extension for porosity in the weld. A disposition to grind out and reweld was given. The reweld was undertaken by using an automatic welder, with which some porosity has also been developed within the weld in the rework area. Additional repairs are being conducted.

4. STATIC TESTING

a. Servoactuators--The four hydraulic servoactuators were functionally checked to determine the rework necessary to provide two acceptable units for the TU-521.01 motor test. The results of the checks are tabulated below.

Actuator S/N	Valve S/N	Valve Condition	Potentiometer Condition	Actuator Condition
1	11	Requires rework No control	OK after cleaning	Internal corrosion-proof checked, OK
2	14	Uncontrolled oscillation, has oil leak	OK	OK
3	28	Operates OK, needs new filter	OK	OK
4	26	Operates OK, needs new filter	OK	OK

On the basis of this check, all four servovalves were removed and returned to Moog, Inc for a more complete analysis. The three units requiring the least expense will be refurbished to provide two working units plus one spare. Actuator units 2, 3, and 4 will be used as is with the refurbished valves.

b. Hydrotest--The TU-521 motor test arrangement drawing was completed and all tooling placed on order during the first quarter. No difficulty is anticipated in meeting the scheduled completion date.

The major components of the hydrotest arrangement are shown in Figure 41. Cover plates are provided for the plenum chamber openings. The igniter adapter plate is used as is with simple plugs in the unused openings. The burst disc assembly will not be installed for the hydrotest. The cover plate used in its place will also serve as the closure for the burst disc operational test to be performed later in the program.

All high points in the assembly have been provided with two bleed lines to eliminate as much trapped air as possible. This will minimize any damage in the event of a minor failure under pressure.

c. Static Testing--The incorporation of a CO_2 quench into one or both of the plenum chambers has been investigated and deemed to be feasible. The CO_2 will flow through a solenoid-operated valve plus two series check valves into one or more plenum chamber openings. These may be separate openings or simply tees off pressure transducer ports, depending upon the flow rates required. The final design will be incorporated on the static test instrumentation drawing. Both the technique and the hardware have been proven on the 156-7 static test.

5. PHASE I PROCUREMENT

All materials required to manufacture the Phase I test motors are on order and will be able to support the program test date. The propellant raw materials were used in the propellant tailoring effort discussed under B. 1 above.

Major test motor components include the plenum chamber, auxiliary nozzle, and igniter assemblies. Procurement was initiated for these components during this quarter. Two plenum chamber assemblies have been ordered as a heavy-wall welded assembly and are 90 percent complete. Delivery is scheduled during June 1966.

b. Hydrotest--The TU-521 motor test arrangement drawing was completed and all tooling placed on order during the first quarter. No difficulty is anticipated in meeting the scheduled completion date.

The major components of the hydrotest arrangement are shown in Figure 41. Cover plates are provided for the plenum chamber openings. The igniter adapter plate is used as is with simple plugs in the unused openings. The burst disc assembly will not be installed for the hydrotest. The cover plate used in its place will also serve as the closure for the burst disc operational test to be performed later in the program.

All high points in the assembly have been provided with two bleed lines to eliminate as much trapped air as possible. This will minimize any damage in the event of a minor failure under pressure.

c. Static Testing--The incorporation of a CO_2 quench into one or both of the plenum chambers has been investigated and deemed to be feasible. The CO_2 will flow through a solenoid-operated valve plus two series check valves into one or more plenum chamber openings. These may be separate openings or simply tees off pressure transducer ports, depending upon the flow rates required. The final design will be incorporated on the static test instrumentation drawing. Both the technique and the hardware have been proven on the 156-7 static test.

5. PHASE I PROCUREMENT

All materials required to manufacture the Phase I test motors are on order and will be able to support the program test date. The propellant raw materials were used in the propellant tailoring effort discussed under B. 1 above.

Major test motor components include the plenum chamber, auxiliary nozzle, and igniter assemblies. Procurement was initiated for these components during this quarter. Two plenum chamber assemblies have been ordered as a heavy-wall welded assembly and are 90 percent complete. Delivery is scheduled during June 1966.

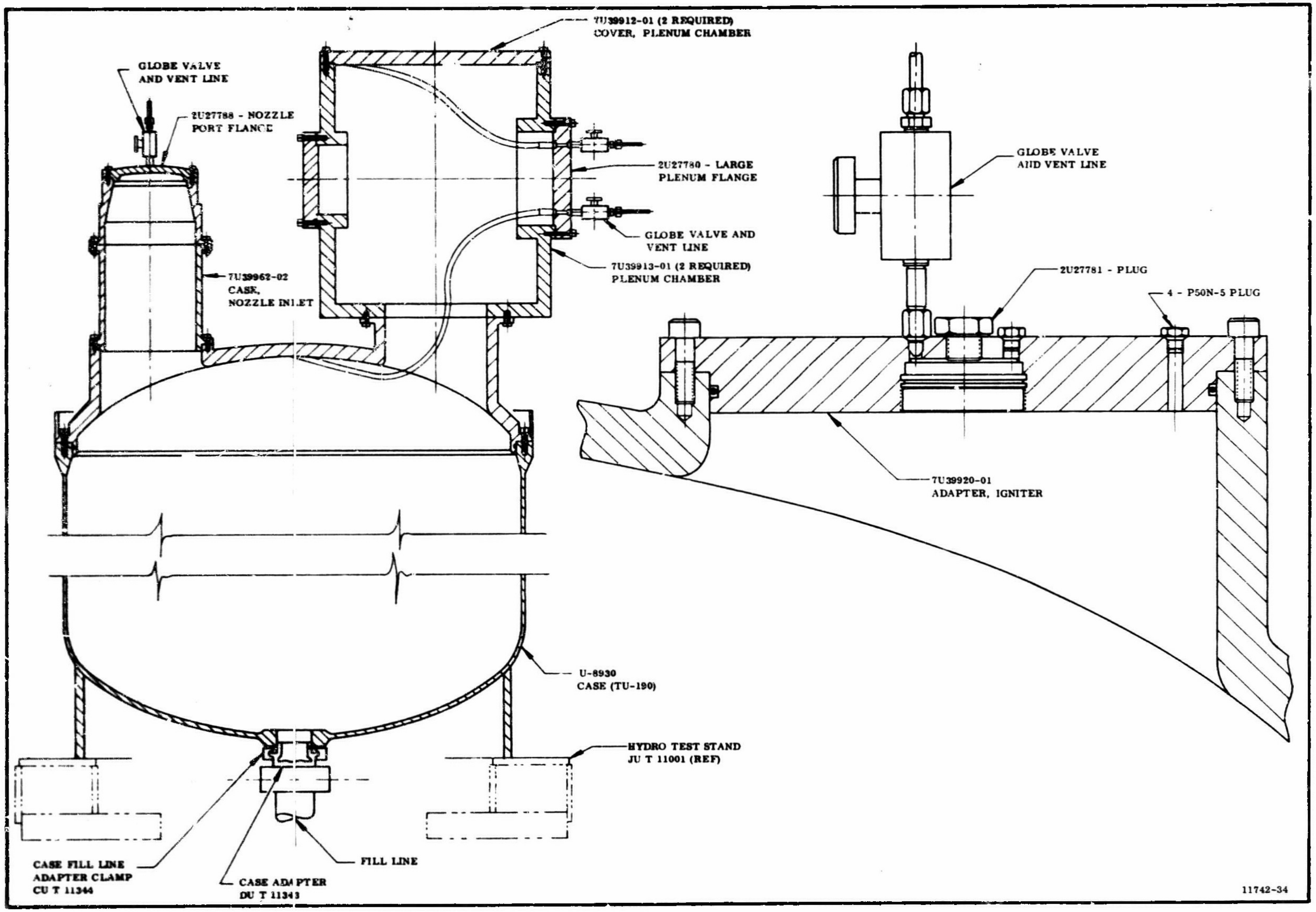


Figure 41. TU-521 Hydrotest Arrangement

Plenum chamber blast tube insulation is being fabricated using surplus Graph-I-Tite rings overwrapped with silica and glass insulation. The blast tubes will be completed during June. Auxiliary nozzle forgings for the nozzle shell and nozzle blast tube will be delivered during June. The nozzle blast tube insulation has been ordered and is of a similar design as the plenum blast tube insulation. Delivery is scheduled for June. The auxiliary nozzle throat will be machined from pressed and sintered 2 percent thoriated tungsten. Components for the auxiliary nozzle assembly are 80 percent complete, and will be delivered during June.

6. COMMON PHASE I AND II COMPONENT PROCUREMENT

The primary common components required for both Phase I and Phase II are the pintle valve and orifice subassemblies. Due to the time required to finalize the pintle valve design, it was necessary to initiate long lead procurement for the materials, including tungsten forgings, pyrolytic graphite, and PTB graphite.

a. Long Lead Procurement--Initial shipments of PTB graphite were made to the pintle valve fabricator during this quarter. It was possible to obtain a 9 in. high billet of PTB sufficient to fabricate the pintle valve body in a single continuous length. Processing of PTB material to fulfill the balance of the order is proceeding per the program schedule. Pyrolytic graphite is scheduled for delivery during June for use in fabricating the orifice assemblies.

The most critical long lead procurement item was the tungsten forgings required for the valve orifice and the pintle shell. Four orifice tungsten forgings were successfully forged during May. These forgings have been delivered and one assembly has been final machined for the orifice assembly.

A major fabrication challenge was anticipated in obtaining the pintle shell forging which has an OD of 7.6 in. and an overall height of 6.7 in. with a wall thickness of approximately one inch. During this first quarter, difficulty was experienced

with the pintle shell pilot tool. The tool tended to tilt during the forging operation, setting up stresses and creating an unacceptable geometry in the pintle forging. A technical review meeting is scheduled with the forging vendor during June to resolve a course of action to obtain delivery of satisfactory pintle shell forgings in support of the program schedule.

b. Pintle Valve Fabrication--Authority was given to the pintle valve manufacturer, Cleveland Pneumatic, to initiate the fabrication of pintle valves No. 1 and 2. These pintle valves are full scale 156 in. size and will use external actuators. Pintle valve fabrication is proceeding on schedule and is over 75 percent complete. Major operations remaining to be completed include machining of the tungsten pintle shell and final assembly. Pintle valve fabrication will be completed during July 1966.

SECTION III

PROGRAM COORDINATION AND REPORTING

Several program coordination meetings were held with the Air Force and major component vendors during this first quarter. The purpose of the meetings was, in general, to obtain approval of component design and to coordinate vendor procurement action.

Supporting these coordination meetings were 14 major transmittals exchanged between Thiokol and AFRPL. The technical meetings, transmittals, and dates follow.

A. TRANSMITTALS

1. Request for long lead procurement approval, 24 Feb 1966.
2. Suggested program plan outline, 1 Mar 1966.
3. Approval for long lead procurement, 7 Mar 1966.
4. Preliminary Program Plan, 18 Mar 1966.
5. Contract Status Report No. 1, 8 Apr 1966.
6. Cost Planning and Appraisal Chart, 14 Apr 1966.
7. Baseline 156-Inch. Motor Pintle Valve Design Layout, 12 Apr 1966.
8. Design of Pintle and Orifice Assemblies Phase I, Test I, 12 Apr 1966.
9. Design 65 In. Diameter Test Motors, 13 Apr 1966.
10. Design for TU-521 Rocket Motor, 3 May 1966.

11. Contract Status Report No. 2, 10 May 1966.
12. Cost Planning and Appraisal Chart, 17 May 1966.
13. Design Changes TU-521 Test Motor and 7U39910 Pintle Valve, 23 May 1966.
14. Duty Cycle for the TU-521.01 Hot Gas Secondary Injection Valves, 27 May 1966.

B. MEETINGS

1. Technical Coordination Meeting held with AFRPL at Thiokol on 13 and 14 Apr 1966 to conduct informal design review on baseline hot gas valve, pintle assembly, orifice assembly, and 65 in. diameter test motor assembly.
2. Program Technical Review Meeting held at Wasatch Division with AFRPL on 12 and 13 May to review proposed design changes to pintle valve and TU-521 motor.
3. Actuator Design Review Meeting held with engineering representatives from National Waterlift on 11 and 13 May to establish firm design baseline for large pintle valve actuators.
4. A program coordination visit to Taylor Forge in Chicago on 20 April was made by Mr. Roy Minert of the Wasatch Division.
5. A pintle valve fabrication status meeting was held with Cleveland Pneumatic on 21 April with Mr. Roy Minert, Thiokol, and Lt. G. Kirby, AFRPL, attending. Final valve design changes were coordinated.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Thiokol Chemical Corporation Wasatch Division Brigham City, Utah 84302	2a. REPORT SECURITY CLASSIFICATION Confidential 2b. GROUP 4

3. REPORT TITLE
Quarterly Progress Report #1
Flight Weight Submerged Hot Gas Secondary Injection TVC System for Large Solid Rocket Motors

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Quarterly Technical Report (QTR) - 15 February thru 15 May 1966

5. AUTHOR(S) *(Last name, first name, initial)*

Paul D. Nance

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 June 1966	93	-------

8a. CONTRACT OR GRANT NO. AF 04(611)-11408 b. PROJECT NO. 623A c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 0716-64-1084 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* AFRPL TR-66-156

10. AVAILABILITY/LIMITATION NOTICES

Qualified requesters may obtain copies of this report for DDC

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
N/A	Air Force Rocket Propulsion Laboratory Edwards, California 93523

13. ABSTRACT

This program was established by the Air Force and Thiokol Chemical Corporation to design, develop, and demonstrate a hot gas secondary injection thrust vector control system (HGSITVC) for large solid propellant rocket motors. The program was initiated on 15 February 1966. Phase I of the program is concerned with the design, analysis, and optimization of a 156 in. diameter motor HGSITVC system. The data from this baseline design will be used to design six test pintle valves for demonstration on 65 in. diameter test motors. Phase II consists of designing a four-valve 120 in. diameter motor HGSITVC system using the basic designs and design data developed under Phase I. The 120 in. diameter test motor will be designed, fabricated, and tested to demonstrate four full scale 156 in. diameter motor pintle valves. The pintle valve will use a proven tungsten-to-tungsten valve seating arrangement and a pressure balance technique to minimize actuation force requirements. A baseline 156 in. diameter demonstration test motor which uses available proven MINUTEMAN hardware was designed this first quarter. The test motor will expose the full scale 156 in. pintle valve to simulated flow and operational pressure environments. In addition, the propellant for the demonstration test motor was tailored to define the required formulation, and the major components for the first Phase I test were ordered. Four satisfactory orifice forgings were shipped.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
____________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
____________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
____________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

1. REPORT IDENTIFYING INFORMATION		DDC ACCESSION NOTICE
A. ORIGINATING AGENCY AFFTC Directorate of Procurement (FTMKR-5) Edwards AFB, California 93523		--- *INSTRUCTIONS* --- **Requester:** *1. Put YOUR mailing address on Reverse of Form.* *2. Complete item 1.* *3. Attach form to reports mailed to DDC.* *4. Use UNCLASSIFIED information only* **DDC:** *1. Complete item 2.* *2. Return to requester*
B. REPORT TITLE AND/OR NUMBER Hot Gas Secondary Injection Thrust Vector Control Demonstration Program Project 2000 (U)		
C. MONITOR REPORT NUMBER AFRPL TR-66-156		
D. PREPARED UNDER CONTRACT NUMBER(S) AF 04(611)-11408		
2. DDC DOCUMENT NUMBER ASSIGNED		
A. AD NUMBER	B. DATE	

DDC FORM 50 MAR 65